F. H. RICHARDSON'S

BLUEBOOK of PROJECTION

qp.

Sept 24 1937

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SOUND SECTION IN COLLABORATION WITH
AARON NADELL

SIXTH EDITION

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ACKNOWLEDGMENT

It is with keen appreciation that I make note of the courtesies and cooperation shown me during the preparation of this, the sixth edition of the BLUEBOOK OF PROJECTION, by the engineering and executive personnel of various equipment manufacturing companies to which I had recourse for specific information and for accuracy of data. As a result of this cooperation so willingly and promptly extended I have every assurance that this BLUEBOOK is not only complete in all the essential details of motion picture projection and sound reproduction but also that it is, by and large, an accurate presentation of what is becoming, almost daily, a more difficult subject and a more exacting profession.

To the following companies, for numerous conferences and for making available photographs for reproduction herein never before privileged for publication, I make grateful acknowledgment:

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I also extend appreciative acknowledgment to the following individuals whose expert advice helped me materially: Edgar R. Wagner; A. H. Kopprasch; J. E. Heney; William N. Douden; George Dobson and Herbert Griffin.

Aaron Nadell, my collaborator, joins me in this acknowledgment. F. H. R.

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I happily dedicate this 1935 edition of my BLUEBOOK OF PROJECTION to the International Alliance of Theatrical Stage Employees and Motion Picture Machine Operators of the United States and Canada in the hope that it will aid its members to further improve the efficiency and quality of their work, thereby giving substantial aid to the motion picture industry and doing honor to themselves.

F. H. RICHARDSON.

FOREWORD

By ADOLPH ZUKOR

Chairman, Paramount Pictures, Inc.

THERE comes in the career of every motion picture that final occasion when all the artistry, all the earnest constructive endeavor of all the man-power and genius of the industry, and all the capital investment, too, must pour through the narrow gate of the projector on its way to the fulfillment of its purpose, the final delivery to the public.

That delivery is a constant miracle of men and mechanism in the projection rooms of the world's fifty thousand theatres. That narrow ribbon, thirty-five millimeters, flowing at twenty-four frames a second through the scintillating blaze of the spot at the picture aperture and coursing at an exactingly precise 90 feet a minute past the light slit of the sound system, demands a quality of skill and faithful, unfailing attention upon which the whole great industry depends.

The projector lens is the neck of the bottle through which all must pass. The projectionist presiding over that mechanism is responsible for the ultimate performance upon which we must all depend.

The projector must not fail and, more importantly still, the man must not fail or permit it to waver in its performance. It is to the tremendous credit of the skill of the modern projectionist that perfect presentation of the motion picture upon the screen is today a commonplace, a perfection that is taken as a matter of course.

FOR more than a quarter of a century now F. H. Richardson, author of this and the Bluebooks that have gone before, has been the philosopher, friend and guide of the projectionists. He began in the nickelodeon days when the two-pin Edison projector was considered a wonderful machine, and he has continued, becoming himself an institution along with the developing art, into this day of the amazing complexities and large responsibilities of the modern projection room, with its maze of machinery and all the delicate, intricate devices that are involved in sound picture reproduction.

It is appropriate that here in this place one who has shared and experienced these years of the building of the screen into its world dominion as an amusement medium should record the industry's recognition of Mr. Richardson's long and diligent service and his valued contributions to the progress of the motion picture art.

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F. H. RICHARDSON

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CHAPTER I.

ELECTRICAL ACTION

(1) The very foundation principle of electrical action is polarity, which is in effect the separation of elements or forces that desire to unite. Just what electricity is no one yet knows, though many theories have been advanced. We do know, however, that if a wire be attached to the positive pole of an operating dynamo or a charged battery, and another wire be attached to the negative of the same instrument, and these two wires be properly attached to a suitable motor, the motor will be caused to operate and produce power; also we know that if the wires be brought into direct contact with each other a shower of sparks will be produced. In other words we can, by means of suitable devices, make positive and negative electricity perform work as the two forces amalgamate.

Only Two Wires

(2) Insofar as concerns electrical action, every electric circuit consists of just two wires (conductors)—a negative and a positive. (3) There may seem to be more, as in the 3-wire system, but upon analysis it is found that the extra wire or wires merely form additional 2-wire circuits, which may be used either singly or together. (4) Each electric circuit consists of one

positive and one negative conductor. Every electric generator (battery or dynamo) may be regarded as having one positive and one negative pole. (5) The positive wire of any circuit represents the positive pole of the distant generator throughout its entire length. The negative wire represents the negative pole of the generator at any point in its length. (6) Attaching a motor or lamp to these wires at any point is exactly the same as attaching them to the generator poles themselves, except for the fact that each wire offers a certain amount of resistance per foot of the length to the flow of current, as will be explained later.

When disconnected from the generator, or when the generator is not in operation, the wires are said to be "dead." The instant they are connected to the poles of a working generator they become "live wires," being charged with "voltage," which means electric pressure, exactly the same as pounds mean pressure in a water pipe or a steam boiler.

Steam confined in a boiler seeks to reach the open air because in so doing it loses its pressure. Positive and negative electricity in a circuit seek to join forces or at least to equalize any difference between them. It was formerly claimed that current seeks to flow from positive to negative. It is now claimed that current seeks to flow from negative to positive. With these scientific arguments we are not especially concerned. The two seek to join forces in order to loose pressure or tension. Our only concern at this point is to give you some understanding of how electrical action may be converted into power. (7) All that anyone yet knows positively is that there is an affinity between the two, or of one for the other if you prefer that expression. (8) The positive desires to become negative, or vice versa, and that "desire" is what we term "polarity" or "voltage." It represents difference in electrical pressure between positive (+) and negative (—).

How Work Is Performed

(9) When steam is confined in a boiler under pres-

sure it seeks to expand its volume and thus lower its pressure. We permit it to enter a cylinder in which is a movable piston on one side of which is steam pressure and on the other side only the pressure of air. The steam (pressure) shoves the piston along to the end of the cylinder, thus expanding its volume, and lowering its pressure. If a load is attached to the piston the load will be moved and power will be produced.

(10) In this action the steam itself is not consumed. The same quantity remains but its pressure has been consumed or reduced, the power produced representing reduction in pressure. Steam is merely the medium through which pressure works. (11) Compression of steam stores up power. This is very similar in action to the compression of a coil spring. Compress the spring and power is stored up therein, which may be made available by releasing the spring and permitting it to expand again. The spring remains but the power is gone. (12) It is much the same with electricity. It is under pressure (voltage), the release of which produces power. When current flows through a lamp or motor, its voltage is reduced, not the current. Exactly the same quantity or volume of electric current that enters the device through one wire leaves it on the other.

(13) Electricity is invisible. Light produced by it is not electricity but merely the evidence of its power. However, we do find its action to be essentially the same as that of water or steam under pressure, hence those two very tangible, understandable things may well be used as a basis of comparison.

(14) Apparently, electricity exists under pressure on one wire of a circuit. Apparently it looses its tension or pressure in the act of entering the other wire. Or perhaps it might be better to say pressure is lost as the two forces, negative and positive, amalgamate or join.

(15) Be that as it may, certainly pressure is lost and we are able to turn pressure reduction into power production by the use of certain devices such as lamps, motors, heating coils, etc. We permit the positive and negative to join in the act of passing through these devices, and

we are able to utilize the pressure reduction to operate them and thus produce power for our use.

Earth and Power Source

(16) Many have the idea that current seeks to escape from the wires and enter the earth. This is not true, except where earth may offer a path or connection between positive and negative of the same dynamo or battery.

(17) The positive and negative of any power source has no affinity for anything except the positive and negative of the same power source.

(18) The positive of one electrical power source, regardless of voltage or capacity, may be brought into direct contact with negative of another electrical power source without result, except to enable the use of the power sources in "series." It will be the same as though two dead wires came into contact. (19) Thoroughly insulate a 5,000-volt dynamo from ground (a thing seldom, if ever, accomplished) and theoretically at least one may stand on wet earth and handle either charged wire without injury. If, however, the other wire has current carrying connection with the earth, the current will leap through the body into earth and through earth to that connection. In this case the presumption is that the path through the body and earth offers insufficient resistance to prevent the flow of current.

Electric Generation

(20) Since in many theatres generators are under the direct supervision and charge of the projectionist, it is essential that he understand not only their mechanical construction, but also their electrical action and the theory upon which electrical generation is based.

(21) There are two methods of generating electric current, namely, the mechanical-magnetic and the chemical. The generator (dynamo) employs the mechanical-magnet; the battery, the chemical method. In projection work, however, the chemical is more largely

employed for storage of power generated by the first named method.

How a Generator Armature Acts

(22) The generator depends for its action primarily upon the following law: "If an electric conductor in the form of a closed circuit be moved in a magnetic field in such manner that the said conductor will cut (pass through or across) a variable number of lines of magnetic force, a voltage will be built up and a current of electricity caused to flow in a direction at right angles to the line of motion of the conductor."

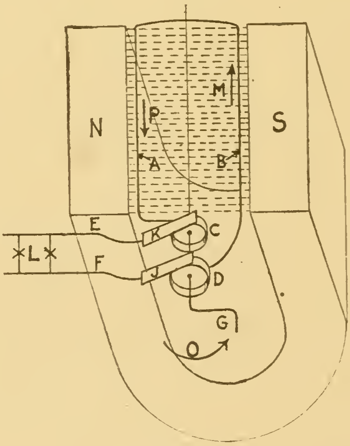


FIGURE 1

Figure 1 is the diagrammatic representation of a dynamo in its simplest possible form. (23) We see a permanent magnet between the poles (N and S) of which flow lines of magnetic force represented by dotted lines. This flow constitutes what is known as magnetic field. Within this "field" is copper wire AB, bent into the form shown, which represents the armature of a generator. One end of this wire is attached to flat-faced metal ring C; the opposite end to a similar ring, D.

Bearing upon the end of each of these rings and in electrical contact therewith are "brushes" K and J, to which circuit wires E and F (positive and negative alternately in this case) are attached. Between these wires lamps L are connected. (24) Examining this diagram it is clear that any current generated may flow through coil AB into one of the brushes KJ, on into one of the wires and through lamps L into the other wire, producing light in the lamps of course. We then have a complete, or "closed" circuit in Fig. 1.

How Generation Carries On

(25) Now if we rotate coil AB by means of crank G in the direction of arrow O, coil side A will pass down and side B upward through the magnetic field, cutting across lines of magnetic force. In so doing the action will (see law previously quoted) generate an electric impulse (current) which will, under the conditions named, flow through the entire closed circuit in the direction indicated by arrows M. P.

All Armatures Generate Alternating Current

(26) Let us now advance a step: in Fig. 1 it is assumed that crank G rotates in direction O. Under that condition current generated will flow toward brush K and wire E. As the coil now lies, it is in the very strongest part of the magnetic field. When it is rotated, one side rises and the other lowers gradually, both not only passing out of the strongest part of the field, but moving more and more in the direction of the lines of magnetic force, hence cutting across less and less and finally none of them. Analyzing this action we see that gradually (the action becomes really very fast) the voltage and consequently the current generated grow weaker, until finally both cease entirely. (27) However since the coil continues to move, side B immediately starts downward and side A upward, so that both again start cutting lines of magnetic force, but in an opposite direction to that of the preceding half-revolution.

Since the current flows in one direction with relation to the magnetic field, it is evident that the current generated in this second half-revolution will not flow into brush C, but instead into brush D, and thus the direction of current flow throughout the entire circuit has been reversed. This reversal will continue with every half-revolution of coil AB. (28) This description assumes the flow to be from positive to negative (+ to —) in accordance with what was until quite recently considered as the action of current. Some scientists now tell us the action is from negative to positive; in that case the story told in Figure 1 calls only for a reversal of direction of the arows.

(29) In the infinitesimal fraction of a second during which coil AB stands in upright position neither side is cutting any lines of force at all; hence the whole circuit is electrically "dead." The lamps continue to maintain partial illumination through the "dead" period because their incandescent parts cannot wholly cool off in so short a time.

Between magnetic poles N and S, current flows continuously in one direction. It changes direction in the coil and circuit only because with each half revolution of the coil its sides change position, or are reversed. (30) This action is different in multipolar generators, because it takes place every time a coil passes through the field of one of the magnetic poles of the machine. The general effect is the same.

How Current is Commutated

(31) We have tried to give you basic understanding of how current is generated in a dynamo armature, and why an armature always produces alternating current. Since a. c. cannot always be used, means have been provided for changing the armature a. c. into direct current before it reaches the circuit wires. This is called "commutation." It is a means by which a. c. is received at the "commutator" of a generator and there transformed or changed into d. c. It is difficult procedure to describe understandably, but we will do our best to make the matter at least reasonably clear.

In Fig. 2 we have two separate diagrams, A and B. In A we see armature coil AB connected to a commutator ring divided into two sections, EF, upon which brushes

CD bear. Outside circuit wires attach to brushes CD, the circuit being completed through lamps G.

If we remember what has been said about the direction of current flow in armature coils with relation to the field magnet, and assume it to be in the direction indicated by the arrows, it is evident that in diagram A the

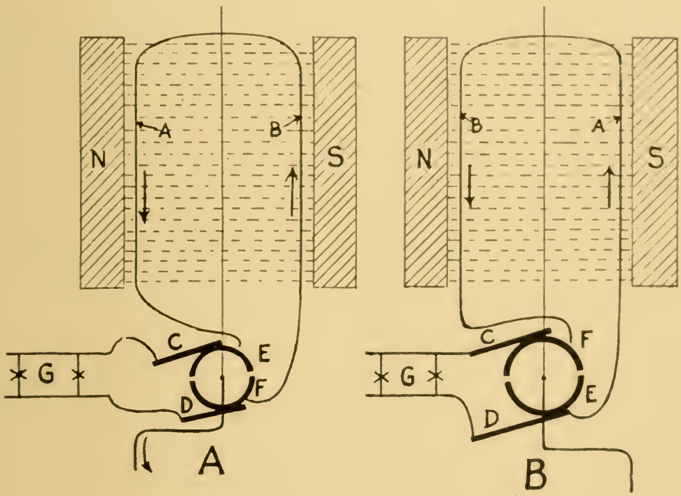


FIGURE 2

flow will be into brush C, through lamps G and back through brush D into coil-side B.

However, noting position of crank A and B, we see that in diagram B the coil has been rotated one-half a revolution, so that coil-side B in diagram A occupies the position in diagram B that coil-side A did in diagram A, hence the current now is flowing into commutator segment F, instead of commutator segment E, as in diagram A. And since brush C is now in contact with ring F and current still flows into it from the same direction as formerly, the current flow in the outside circuit is still in the same direction as it was in diagram A.

Commutator segments E and F will be in contact alternately with brush C, hence the outside circuit will have current constantly flowing in one direction. This is termed "commutation" of current. In modern dynamos the commutator consists of as many copper bars or segments as there are coils like AB in the armature.

(32) In practice all coils are interconnected with each other through the commutator segments. Failure to understand that there can be any connection between positive and negative brushes located at opposite sides of the commutator bars may puzzle the student. Just remember there is an interconnection, and the current generated by each coil will seek its own coil again after having passed through the external circuit.

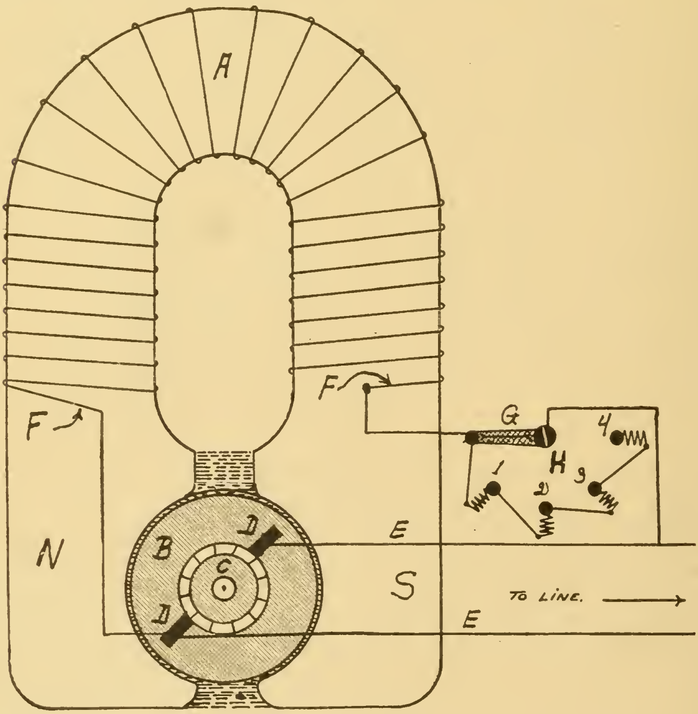


FIGURE 3

THE GENERATOR

We use the term "dynamo," though properly that term is only applied to machines producing direct current, those producing alternating current being known as "alternators."

(33) Fig. 3 shows various integral parts of what is

known as a "two-pole, direct current, shunt wound generator or dynamo." (34) N is the north and S the south pole of its permanent magnet; FF its field winding, C its commutator, DD the brushes, B the armature, H the field rheostat and EE the outside circuit to which current is supplied by the generator. 1, 2, 3 and 4 are resistance coils of the field rheostat, upon either contact button of which the movable arm just under G may be made to rest. As the arm is now it is plain that all these coils are "cut out," there being no resistance in series with field coil FF.

(35) Magnetic force like electromotive force represents pressure. (36) When a wire is coiled around a suitable iron core in close proximity thereto and a. c. is sent through the wire the iron will be magnetized; (37) the magnetizing power exerted will be in exact proportion to the current strength (E.M.F.) and the number of turns the wire makes. (38) The density (pressure) of a magnetic field is usually spoken of and considered as the number of lines of magnetic force per square inch. The greater the magnetic intensity of a field the greater the number of lines of force per unit area.

(39) The capacity of such a machine would, within certain limits, depend upon (1) the strength of field magnet NS, since that controls the number of lines of magnetic force the commutator coils will cut during each revolution of the armature. (2) The number of turns of each armature coil and the number of coils mounted on the armature. (3) Number of rotations of the armature per minute. Each of these items, you will observe, has to do with the number of lines of magnetic force that will be "cut" per second. Other things enter, such as, for instance, the kind of armature core, size and winding of magnets, etc., but our purpose here is only to briefly explain the principles upon which the electric generator operates. With infinite variations in method, these are always the same.

(40) In Fig. 3, N and S is a "permanent magnet" by which is meant that the magnet retains some of its magnetic force when the machine is not in operation, and

therefore electrically "dead." (41) This very weak force is termed "residual magnetism." Generators which have non-residual magnets must, at starting, have their magnets excited by a small generator, usually attached to the machine itself. Residual magnetism is much too weak to enable the machine to build up a commercial voltage. It merely has strength to enable the machine to start operation.

In Fig. 3 we see field winding FF coiling around a portion of magnet NS. With field rheostat G as shown there is no resistance in series with field winding FF. The engine or other power source starts armature B rotating whereupon, with the line switch open and therefore practically no resistance in the circuit, the armature coils begin cutting such lines of force as the residual magnetism supplies. A very weak current is thus generated, all of which flows around field coil FF.

(42) Now if alternating current is sent around magnet NS through such a coil as is shown (FF), the immediate result will be to strengthen the magnet itself, and thus to increase the number of lines of magnetic force cut by the armature coil each revolution or per second, so that the magnetic strength will be further increased. (43) This proceeding, if unchecked, will go forward until the magnet has reached the "point of saturation," which means that its strength cannot be further increased.

(44) In practice, however, the process goes forward until the commercial voltage has been built up, whereupon the switch controlling outer circuit EE is closed, and sufficient resistance cut in series with winding FF (by moving the lever just below G, Fig. 3) to supply sufficient magnetic strength to enable the armature to maintain the required line voltage. In practice this latter is, in modern machines, done automatically by the machine itself.

(45) Modern generators for the most part have more than two magnets, but in effect only one N and S pole. (46) The added magnets enable the machine to produce the required amount of electrical energy at the desired

frequency of cycle with less massive construction and (or) lower armature speed.

D. C. and A. C.

Direct current, commonly termed d. c., flows continuously in one direction. Of late the scientists have favored the view that the direction of flow is from negative to positive. In theory the flow is outward on the negative wire until a crossing point is found through some device, usually for producing heat, light or power, and then back to the generator over the positive wire. As a matter of fact it is not definitely known that anything really does flow along the conductor. Molecular bombardment is one widely accepted theory. It will serve our purpose to assume that there is an actual flow and that it is from positive to negative.

Alternating Current

(47) A. c. is the accepted abbreviation for alternating current. It is, as has already been explained, the current always generated in dynamo armatures. (48) It flows first in one direction and then in the opposite direction, (49) the change of direction occurring in ordinary commercial practice from 50 to 120 times per second. (50) Although d. c. is decidedly the better of the two for lighting purposes and may be used for heat and power production, a very large percentage of power plants distribute a. c. The novice naturally wonders why this is.
(51) Chiefly it is the ease with which a. c. voltage may be either raised or lowered, after generation, at any desired point along the lines. This cannot be done with d. c. except by the use of expensive machinery having moving parts and requiring more or less constant attention.
(52) Power, as expressed in horsepower, is found by multiplying voltage by amperage and dividing that product by 746. (53) The product of volts and amperes is "watts." Seven hundred and forty-six watts equals one electrical horsepower, ordinarily abbreviated

HP or H.P. Thus 100 volts times 10 amperes equals 1,000 watts, or 1,000 ÷ 746 = 1.34 HP.

In a. c. circuits this rule applies only with certain modifications.

(54) You will learn later that the necessary diameter of wire used is governed by the number of amperes and not by the voltage. A No. 8 wire, for example, can carry only 50 amperes without overload but it may carry that amperage at low or high voltage. (55) Now 50 amperes at 100 volts pressure would be only five thousand (50 × 100) watts, or less than seven HP whereas 50 amperes at 1,000 volts pressure would be 50,000 watts or more than 67 HP. (56) To convey 67 HP at 100 volts would require No. 4 rubber-covered wires, expensive in themselves and expensive to install.

(57) A. c. may be generated at ordinary commercial voltage, say 110, and merely by passing it through a relatively cheap machine (transformer) having no moving parts, requiring practically no attention at all and with about 95 percent efficiency, the voltage may be raised to any desired pressure. It may then be conveyed to the point where it is desired to use it, and there by passing through a similar machine (transformer) having a different winding, the pressure may again be reduced as low as may be desired, usually 110 volts. Then too, there are advantages in certain types of a. c. motors. Broadly speaking, the reason why a. c. is so generally used is the economy in transportation, though there are many minor reasons.

Alternating Current Action

(58) As has been said, a. c. flows first in one direction, then flows in the opposite direction for an exactly equal space of time. These changes in direction of flow are called alternations. (59) Two alternations (the current starting from horizontal line 0, Fig. 4, following line BC to point 2) form one complete "cycle." (60) The number of cycles per second are termed the frequency of the current.

The frequency of commercial current varies. (61) It has been found that 50 or 60 cycle current is about as low as may be used for lighting without visible flicker in the light. Twice each cycle the voltage and amperage drops to zero, hence there is no light source energy and the only light available during that period comes from the lingering incandescence of the filament. At 60 cycles the action will be rapid enough to tide over without visible flicker. (62) On the other hand frequency as low as 25 cycles per second has very distinct advantages in the operation of motors. Frequencies lower than 25 are not suited for motors and poor for lighting. (63) Almost all commercial power plants which supply both power and light are producing 50 or 60 cycle current; where power is the chief requirement the frequency may be as low as 25.

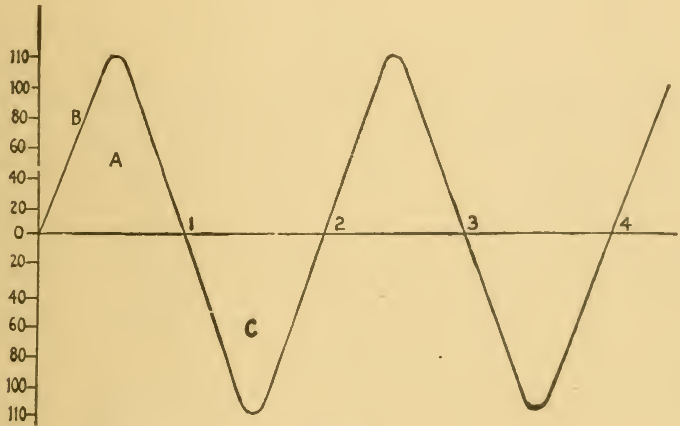


FIGURE 4

(64) (a) There is flicker in any light produced by a. c., no matter how rapid the cycle. At 60 cycles or higher, however, the action is so very rapid and the drop in illumination so slight that the human eye cannot discern it. (b) Each period of time between changes of direction is an alternation. (c) Two alternations are one cycle. (d) The voltage of a. c. may be raised higher or reduced to any desired point merely by causing the current to pass through a properly constructed trans-

former having no moving parts. Changing the voltage has no effect on the frequency.

A. c. action usually is expressed diagrammatically as shown in Fig. 4. (65) The vertical line represents voltage (E.M.F.). The horizontal time line represents four alternations. Triangles A and C each represent one alternation; the two together, one cycle. If the current be 60 cycle (60 cycles per second) then the distance from 0 at the left end of horizontal time line to 1 would represent one-half of one-sixtieth, or 1/120th of a second of time.

(66) Line B represents voltage or current flow. Current and voltage start from line 0 at zero, raising to 20, 40, 60, 80, 100 and 110 volts in 1/240th of a second. It is then at its maximum and instantly begins to sink back to zero at 1.

We now see that line B represents two things: time (1/120th of a second between 0 and 1) and voltage through successive stages up to 110 volts, which is maximum. The same action now takes place, as represented by triangle C, except that polarity is reversed, and so on indefinitely. (67) Where the triangular lines cross the horizontal line is the point where the wires of armature coil AB, Fig. 1, stand above each other and are moving in the same direction as the lines of magnetic force, cutting none of them and generating no voltage.

Two and Three-Phase Current

We have been describing what is known as single-phase a. c., in which, as has been explained, the voltage and amperage both sink to zero at the end of each alternation, resulting in a strong pulsating effect, both in light and power production. (68) This may be avoided in a. c. by the joining of two single phase currents of the same frequency (time per alternation or cycle) and voltage, (69) the two being so coupled together that the low period (0 Fig. 4) of one comes at the high period of the other.

Suppose we have two generator armatures producing exactly equal voltage and frequency (see Fig. 1) so coupled together with chain or gearing that the low zero period of one came at the high period of the other. If these two currents are used together in a motor, each current actuating a different field, it is evident that the pull on the motor armature will be much more than with a single a. c. current. This is known as 2-phase current. The action or relation of the two currents is diagrammatically represented at A, Fig. 5. The voltage of such a system is never at zero.

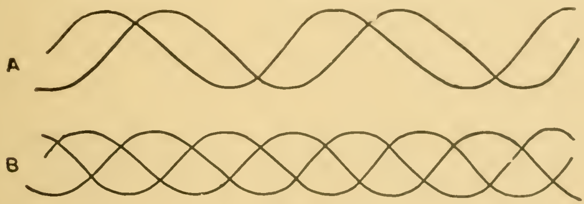


FIGURE 5

If we couple a third generator in such manner that the alternations of the three are equally spaced, we shall have 3-phase current action as shown at B, Fig. 5, which will approach the effect of d. c. in its non-pulsating characteristics.

(70) Two-phase current is transmitted ordinarily by two entirely separate two-wire circuits. This method provides a much more even pull to motor armatures, and consequently a more even effect to any apparatus to which it may be connected, than can be obtained from single-phase current.

(71) Three-phase current requires only three wires for its transmission. It forms an ideal system for the distribution of electrical power. It provides an even pull on motor armatures.

Following are definitions of electrical terms which users of the BLUEBOOK will find valuable and instructive.

POLARITY

(72) Wires attached to opposite terminals of an electrical power source are capable, when connected to some suitable device, of producing power to perform

work. Connect them to an incandescent light globe, for example, and light will be produced by the heating of its filament to incandescence. Connected to a motor they will cause its rotary element to revolve against the resistance of a load, thus producing power. Connect them to a suitable resistance coil and heat will be produced.

This electrical condition is termed Polarity. It represents the electrical affinity a wire negatively charged has for a wire positively charged from the same power source. It is the effect of what we call electrical pressure, measured in volts.

Negative and Positive

When a circuit is charged with direct current one conductor is always negative; the other positive. (73) When a circuit is charged with alternating current each wire is alternately negative and positive many times each second. In the case of 60 cycle current each wire is negative 60 times each second and positive 60 times each second.

Voltage

(74) Voltage, also known as electro-motive force, is commonly abbreviated into E.M.F., or just E. Electric current is generally considered as having both pressure and volume. In its action it is very similar to that of water. Water, however, may be made the subject of physical examination. We can watch its action. We can feel it or weigh it. Electricity, on the other hand, is an impalpable substance or force. It is without appreciable weight, though scientists assure us it has an infinitesimal weight.

We cannot see it except in the form of light which is not electricity but a product of its power. We cannot feel it except in the form of a shock, which again is not electricity but its effect in passing through the tissues of the body.

Voltage, in its action, corresponds to pressure applied to water in a pipe, or to steam in a boiler. An ordinary dry cell (battery) such as is used to ring bells has approximately 1.5 volts pressure. It imparts that pressure to the wires attached to its terminals. (75) If a properly insulated wire is attached to each terminal of a dry battery cell, both wires will have a pressure of approximately one and one-half volts at any point of their length, excepting only the pressure used up in moving the current from its point of generation to the point where the voltage is measured. (76) If we connect the positive of one battery cell to the negative of another cell, or the positive of one dynamo to the negative of another dynamo, a series connection is formed as per Fig. 6, and a circuit connected to the other two poles of the combined cells or dynamos will have the full combined voltage charge of both cells or dynamos. If the cells each have 1.5 volt charge, the circuit will carry a 3-volt charge. If the

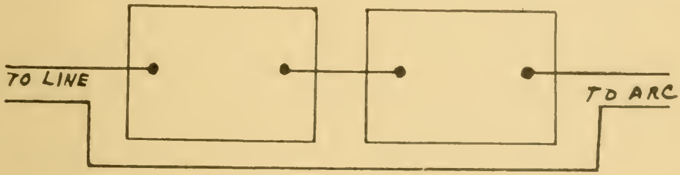


FIGURE 6

dynamos each have 110-volt charge, the circuit will carry a 220-volt charge. The amperage, however, will equal only the amperage capacity of one of the cells or dynamos.

(77) If one wire of a circuit is cut and one end connected to the positives and the other to the negatives of two or more cells or dynamos as per Fig. 7, the circuit formed by the wires will have a voltage charge equal only to that of one of the cells or dynamos, but the full amperage capacity of all cells or dynamos thus connected will be available. This is a parallel or multiple connection, the two terms having exactly the same meaning. Series connection increases pressure. Parallel connection increases amperage. Any number of cells (or dynamos) of equal voltage and other characteristics may be connected either way. Each unit connected in series

will raise the total voltage by its own voltage. Parallel connection will not alter the voltage but will raise the current to any desired part of the full capacity of the additional cells.

Remember that voltage acts only between the negative and positive of the same power source, and that the positive attached to one power source has no affinity for the negative attached to another power source. Moreover, neither positive nor negative has any affinity for the earth, save that the earth may furnish it a path to opposite polarity of the same power source. The idea that current generated by a dynamo seeks to escape from it, or from the wires connected to it, into the earth, is wrong but for the one exception noted above.

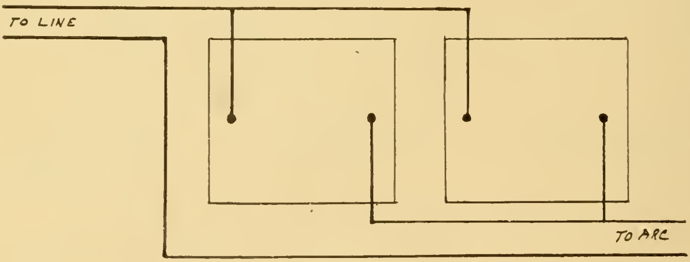


FIGURE 7

AMPERE

(78) This term is used to denote quantity or volume. Amperes represent the volume of current flowing in a circuit, exactly as gallons per second represent the quantity of water flowing through a pipe.

HOW WORK IS ACCOMPLISHED

(79) Work is performed by voltage causing volume (current) to flow against electrical friction. When water, under pressure turns a wheel, it is not the water that is consumed, but its pressure. (80) The higher the pressure or volume the greater the amount of work any given volume of either electricity or water may be made to perform. However, it is not the volume, but the pressure which is consumed in performing work.

If we supply an engine with steam at 50 pounds pressure it will do a certain amount of work. If we raise the pressure to 100 pounds its capacity for work will be doubled, though using only the same number of cubic inches of steam. In both cases the pressure and not the steam is consumed.

It is the same with electricity. (81) Ten amperes of current at 50 volts pressure represent a certain definite quantity or amount of electrical energy, namely 50 × 10 = 500 watts. Ten amperes at 100 volts represent exactly twice as much. Twenty amperes at 50 volts would represent the same amount as ten amperes at 100 volts. (82) Watts represent electrical energy, and watts are volts multiplied by amperes.

The point we wish to make is that (83) amperage or volume is merely the vehicle through which pressure (voltage) works, and that (84) it is voltage or pressure that is consumed in the production of power. (85) The horse power performed by an electric current is represented by voltage times amperes (watts) divided by (86) 746 (watts), which is one horse power of electric energy, therefore volts × amperes ÷ 746 = horse power.

The Ohm

(87) In passing through a pipe water meets resistance due to friction with sides of the pipe. If the pipe walls are rough friction will be greater.

(88) Current passing through metal meets resistance. If the metal is a good conductor the resistance will be low; if the metal is a poor conductor the resistance will be high.

(89) Resistance tends to retard the flow of either water or electricity. Electrical resistance is measured in ohms. (90) It produces heat in the conductors in proportion to the amount of resistance the current must overcome. In other words the power consumed or used in overcoming resistance is transformed into heat. (91) That is why wires become hot when too much current (overload) is passed through them. (92) Resistance increases rapidly as a wire becomes overloaded. (93)

That is the reason why wire capacity tables are necessary.

(94) Having a wire of given diameter, the resistance offered to current flow increases as (a) current flow is increased; (b) as diameter of the wire of other conductor is decreased, and (c) as the length of the wire is increased. (95) Conversely, resistance becomes less as (a) current flow is increased; (b) as wire diameter is increased or (c) as the distance the current must flow through the wires is decreased. (96) In considering resistance the length of both wires of a circuit through which the current must flow must be taken into account. (97) Resistance in copper circuits is calculated as follows: Combined length of both wires in feet multiplied by 10.5 (see resistance figures of copper circuits) and the result divided by the cross section area of the wire, expressed in circular mills.

The Watt

(98) Watt is the unit of electrical power. It is the unit used to express the amount of energy expended. (99) A kilowatt is one thousand watts. It is the term used to express electrical power in large quantities. (100) A kilowatt hour is one thousand watts (1 K.W) used during a period of one hour. (101) Watts are calculated by multiplying the number of amperes flowing by the voltage. Thus, 100 amperes × 110 volts would be 11,000 watts, which make 11 kilowatt hours (11 KWH). A slight correction is sometimes necessary in a. c. circuits. (102) If used for ten hours continuously it would be 110 kilowatt hours (110 KWH). Expressed in horsepower 1100 watts would be 1100 ÷ 746 (watt in one horsepower) = 1.4744 horsepower (HP).

Use of Terms in Calculations

In order to arrive at certain results the projectionist must often make calculations involving electrical terms just explained. This is particularly true in small theatres where reliable measuring instruments (volt meters, ammeters, etc.) are not available.

(103) In calculating the resistance of a projection

circuit the projectionist must remember that the resistance is not confined to the rheostats, or whatever machine takes its place. (104) A considerable proportion of it is in the light source itself, including the carbons, wires, switches and other elements. If these elements are in good condition the resistance they offer singly or collectively is small enough to be disregarded in calculations dealing with an arc light source. The resistance of the light source itself must not be ignored or it will result in a serious error.

(105) In making electrical calculations it is customary, for the sake of brevity, to use the letter E, I and R to express respectively, electromotive force (voltage), current flow in amperes and resistance in ohms, thus: E = Voltage, I = Amperes and R = Ohms.

(106) In formulas, $\frac{E}{I}$ means that the number E represents is to be divided by the number represented by I. Suppose E equals 110 volts, and I represents 25 amperes. We then have 110 ÷ 25 = 4.4, which would represent ohms. (107) Should two or more letters with nothing between them be above or below the line, it means they are to be multiplied thus: $\frac{EI}{R}$ means that the number represented by E is to be multiplied by the number represented by I and the product divided by the number represented by R. $\frac{E\text{-}20}{I}$ would mean that after 20 has been subtracted from the number represented by E (voltage), the result is to be divided by the number represented by I (current in amperes).

Ohm's Law

(108) Ohm's Law is a very simple and easily understandable formula. It reads: The number of amperes flowing will always be equal to pressure in volts divided by resistance in ohms. That is the basis, but it naturally

follows that if E (voltage) divided by R (resistance in ohms) equals I (amperes flowing), then I multipled by R must equal E; and E divided by I must equal R. These equations are expressed as $\frac{E}{R} = I$; $I \times R = E$; $\frac{E}{I} = R$. It works out as follows: (109) If an incandescent lamp bulb filament requires half an ampere at 110 volts to build up the required light value, what resistance of the filament is necessary to restrict current flow to one-half ampere? The answer is $\frac{E}{I} = R$. Substituting figures we have $\frac{E\ 110}{I\ \ .5} = 220$ ohms. (110) If we reverse the problem, knowing the resistance in ohms and the voltage and wishing to ascertain the current flow in amperes, we would have $\frac{E}{R} = I$ or $\frac{110}{220} = .5$ of an ampere. Again, knowing the resistance in ohms and the amperage, we would have $220 \times .5 = 110$ volts. This simple formula is the basis of many electrical calculations.

Rule o' Thumb

(111) In using Ohm's Law what is known as the "Rule o' Thumb" is a convenient assistant to memory. It is simple. Write the formula $\frac{E}{IR}$. Cover the letter representing the quantity desired. What remains will provide the answer, thus: if we cover the R we see that $E \div I = R$. If we cover the E we have $I \times R = E$. If we cover the I we then have $E \div R = I$. In using this formula on projection circuits the upper letter must be written as *E minus the arc voltage or "arc drop."*

RESISTANCE

1. What does current encounter when flowing through a conductor?
2. Explain Figure 8.
3. At what point does a water pipe reach its normal capacity?
4. If a water pipe be overloaded what will be the result?
5. Basing your answer on what has been said about water pipes, what is it that increases or decreases resistance in an electric circuit?
6. Is there any relation between voltage and wire diameters?
7. Could a wire the diameter of a silk thread be charged at 40,000 volts?
8. How much power would one-half ampere at 40,000 volts represent?
9. How much power would 40,000 amperes at 0.5 of an ampere represent?
10. To what is resistance to current flow due?
11. Do different metals offer different resistances to current flow?
12. Taking the resistance of pure annealed copper as 1, name the resistances of silver and commercial copper.
13. Working at or under normal capacity, is rise in temperature of copper wire perceptible to us through physical contact?
14. What determines the normal capacity of copper wires?
15. What will happen if circuit wires are overloaded? Are overloaded circuits expensive and dangerous?

Resistance and Temperature, page 36

16. In what conductor does resistance decrease as temperature rises?
17. Compare the resistance of carbon lamp filament when cold and hot.
18. To what is increase and decrease in resistance proportional?
19. Upon what basic temperature are all resistance calculations based?
20. For what is the temperature coefficient used?
21. Upon what basis are resistance tables constructed?

22. What is meant by a "mil-foot" as applies to resistance?
23. Knowing the temperature coefficient, how may the resistance of a wire be calculated at any temperature?

Loss Through Resistance, page 37

24. Does power used in overcoming resistance represent loss?
25. Is high resistance in an electric circuit ever necessary?
26. What is one important function of the projectionist?
27. What should the projectionist do immediately upon taking charge of a projection room?
28. Up to what point does the resistance of conductors change but little?

Rheostatic Resistance, page 38

29. What function does the rheostat perform?
30. What becomes of the power (voltage) broken down (consumed) by rheostats?
31. Why must the supply pressure (voltage) be higher than the arc voltage?
32. How is arc stability secured?
33. Is waste of power necessary to secure stability of the arc?
34. How can waste power sometimes be saved?
35. What may be qualified roughly as waste?

Resistance Elements, page 40

36. What should be the maximum resistance element temperature?
37. What constitutes the two resistance elements chiefly employed?
38. How are resistance elements mounted and insulated?
39. What controls the amount of resistance offered?
40. What allowances must be made as to new wire coil or cold grid resistance.

Coil and Grid Rheostats, page 41

41. Name the relative advantages and disadvantages of coil and grid rheostats.

Inspection, page 42

42. Is periodic inspection necessary?
43. Of what should such inspection consist?

Location, page 42

44. Do rheostats generate high temperature?
45. Should rheostats be located near inflammable material of any kind?
46. Why should their location be outside the projection room in warm climates?
47. Why should rheostats not be located on the projection room floor?
48. What may be done if a rheostat delivers too little or too much amperage?

Rheostat Connections, page 43

49. May rheostats be connected in either series or parallel?
50. Explain the series and the parallel connection and their effects.
51. May rheostats of unequal voltage or amperage capacity be connected in series or parallel?

A.C. and D.C. Rheostats, page 44

52. Is there any such thing as an "a. c." or "d. c." rheostat?
53. What difference results if the same rheostat be used on a. c. and on d. c.?
54. Why is it bad practice to use a rheostat to control a.c. projector light source current?

Adjustable Rheostats, page 45

55. What is meant by a "fixed resistance" rheostat?
56. Describe an adjustable rheostat.

Calculating Resistance Requirement, page 46

57. How may the resistance in ohms required to pass a desired amperage be calculated, the supply voltage being known?

Overload, page 46

58. What will be the result of overloading resistance elements?
59. What happens if there is too much overload?
60. At what maximum temperature, by Fahrenheit scale, should resistance be permitted to operate?
61. How may projectionists judge, roughly, when maximum permissible temperature has been reached?
62. Is operation of rheostats below capacity true economy?

Testing for Ground, page 47

63. Describe method of testing for grounded coil or grid.

Ballast Resistance, page 49

64. Why is ballast resistance necessary?
65. What is meant by the "negative temperature characteristic"?
66. What would happen if an arc were connected directly across a constant voltage circuit without either ballast resistance or transformer impedance in series with it?
67. To what is the voltage drop across resistance or impedance equal?
68. Does the voltage absorbed by resistance or impedance increase with increase in current flow or vice versa?
69. In what manner is the action of an arc stabilized by ballast resistance or impedance?
70. What happens as the arc length increases?

CHAPTER II.

RESISTANCE

(1) When electrical current passes through a circuit it encounters resistance, in the same way water does when flowing through a pipe.

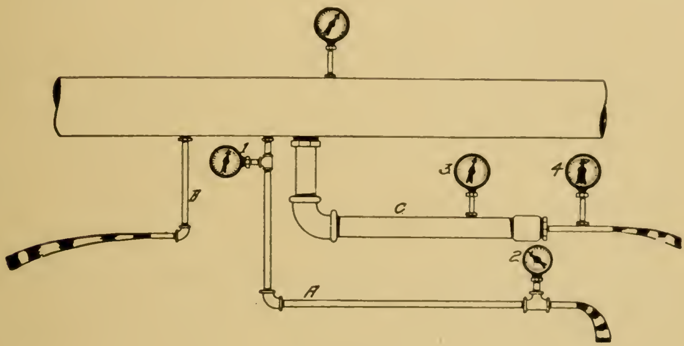


FIGURE 8

(2) Fig. 8 shows pipes A and B of equal diameter and of equal smoothness inside. Both receive water at the same pressure. Pipe B, being much shorter, has much greater pressure at its open end. This illustrates the effect of pipe length in resistance. Pipe C provides practically full pressure up to its point of jointure with the smaller pipe, although the smaller pipe is open and discharging its full capacity of water. In such case the resistance of the small pipe, per unit of length, would be high; that of the large pipe, very low. It is due to difference in the rapidity of the flow of water in the two pipes.

Electrical circuits are similar in their effect upon electric currents. The voltage drops progressively as the distance from the generator increases. The total resistance offered is dependent upon the length of the circuit. If it is long the resistance may be considerable, especially if the circuit is working at capacity. If overloaded it becomes very heavy.

A water pipe of given diameter will convey water at any pressure sufficient to move the liquid without bursting the pipe. (3) However, a pipe of given diameter will convey only a certain volume of flow (number of gallons per minute) without excessive friction or resistance, regardless of the pressure. Beyond that point the pipe is overloaded. When the point is reached where resistance to flow becomes too great, the pipe has passed its normal capacity.

(4) More water may be forced through despite excessive resistance but only at the expense of increased power consumption, which is largely wasted. If more water must be had it becomes necessary either to waste power by overloading or to increase the diameter of the pipe. By increasing the pipe diameter the friction or resistance to the water flow is decreased.

The length of the pipe must also be considered. Since resistance comes from friction between the water and the walls of the pipe, it follows that the greater the pipe length the greater the total friction. Hence, with a given rate of flow, as the length of pipe is increased, resistance is increased; if the length of the pipe is decreased, resistance is decreased.

We increase resistance by (a) increasing the volume of water, (b) by reducing pipe diameter, (c) by increasing pipe length or (d) by increasing roughness of interior walls of pipe.

We decrease resistance by (a) decreasing volume of flow, (b) increasing diameter of pipe, (c) decreasing pipe length or (d) making interior walls of pipe more smooth.

What has been said of the action of water flowing through pipes under pressure is equally true of current flowing through metallic circuits.

(5) If we substitute circuits of wire for the water main and wire circuits for pipes E, A and G, in Fig. 8, and substitute voltmeters for the pressure gauges, with lamps or motors instead of the open ends of the pipes,

we will get the same relative results in loss of pressure (voltage) when current is sent through the circuits up to the normal capacity of the wires.

(6) In electrical action, the pressure, measured in volts, has absolutely nothing to do with wire diameter. If it is properly insulated, a wire of any diameter may be charged at one or one million volts. (7) We may convey current at 40,000 volts on a wire no larger than a silk thread. The amount or volume of current, measured in amperes, which such a wire would convey would be very small; but since power, measured in watts, is the product of voltage and amperes, a very small amperage under 40,000 volts pressure might represent a considerable amount of power. (8) As a matter of fact, .5 of an ampere at 40 000 volts would be 40,000 × .5 = 20,000 watts or (20,000 ÷ 746), a little more than 26 horse power. (9) 40,000 amperes at one-half volt would also represent 20,000 watts.

(10) In passing through wires, electric current encounters resistance in exactly the same manner as water in a pipe. Friction is largely due to the composition of the wires. (11) Different metals offer different amounts of resistance to electric current. Taking the resistance of pure silver and copper as one (1), the resistance offered by certain metals are as follows: (12)

Pure copper	1
Silver	1
Aluminum	1.5
Commercial copper	1.559
Platinum	6
Steel	7 to 8
18 percent Nickel Silver	19
30 percent Nickel Silver	28

The foregoing table refers to the amount of resistance each metal offers as compared with pure annealed copper. For example, 18 percent nickel silver offers 19 times as much resistance as pure copper. In overcoming the resistance of wire circuits current produces heat, (13) but so long as the normal capacity of a copper wire is not exceeded, the heat is perceptible only to a sensitive thermometer. A wire of any given composition and diameter will convey a certain amperage at any voltage without excessive resistance, exactly the same as a water pipe of given diameter and roughness of walls will convey a certain definite number of gallons of water per minute without undue resistance. (14) The point where resistance in a wire begins to rise above normal marks the normal capacity of copper wires. (15) Beyond that point the resistance becomes excessive. Pressure used to overcome resistance appears in the form of heat.

If we attempt to force wires in excess of their rated capacity as shown by the underwriters' table of figures, they will generate heat, becoming red or even white hot, finally fusing and thus stopping the current flow, sometimes starting fires. Certainly the insulation will be quickly injured and perhaps entirely ruined. Overloading circuits is expensive and dangerous.

Exactly as in the case of water pipes, with any given current flow, resistance is decreased (a) as the wire diameter is increased, or (b) as the wire length is decreased or (c) as its composition is changed to one of greater conductivity. Resistance is increased with (a) decrease in wire diameter (b) increase in length of wire (c) change of wire composition to one of less conductivity.

Resistance and Temperature

(16) The resistance of everything used for the conduction of electric current in projection work increases as its temperature is raised; only carbon is excepted from this rule. With carbon the rule is reversed. Increase in temperature lowers its resistance. (17) The filament of a carbon filament incandescent lamp offers about twice the resistance when it is cold than at normal operating temperature. Incidentally it might be remarked in passing that the resistance of insulation materials and liquids is usually decreased as temperature increases.

(18) The increase or decrease of resistance presented

by various metals to the passage of electric current is directly proportional to the increase or decrease in temperature. (19) All resistance calculations are based on a normal temperature of 75 degrees Fahrenheit which equals 24 degrees centigrade.

(20) To calculate resistance of metals, what is known as the "temperature co-efficient" is used. (21) The tables of wire resistance are based upon the resistance offered by a mil foot (22) (one foot of wire of same composition as that being tested, 1/1000 of an inch in diameter) of the wire at normal temperature (75 degrees Fahr.). The co-efficient is the fraction of an ohm change in resistance offered for each degree of change in temperature.

To Ascertain Resistance

(23) To calculate the resistance of any wire its temperature co-efficient must be known. Multiply the co-efficient by the number of degrees of its temperature away from normal, and add the result to or subtract it from the resistance at normal temperature, depending upon whether the temperature is higher or lower. Assuming the temperature co-efficient of a metal to be .001 and resistance at normal temperature 10 ohms per mil foot, what will be resistance at 175 degrees? We find the difference in temperature to be $175 - 75 = 100$ degrees. Since resistance increases .001 per degree increase in temperature we have $.001 \times 100 = .1$ of an ohm. Multiplying resistance at normal temperature, 10 ohms, by fractional increase .1, we have $10 \times .1 = 1$ ohm increase; hence if the total resistance at normal be 10 ohms, the resistance at 175 will be 11 ohms per mil foot.

Loss Through Resistance

(24) Resistance is power dissipated and lost. (25) Some resistance is unavoidable and high resistance is necessary under certain conditions but (26) it is an important function of the projectionist to eliminate all unnecessary resistance, conserving electric power by preventing its waste.

(27) One of the first duties of the projectionist upon taking charge of a projection room is to determine whether or not the various circuits have sufficient capacity to convey the current without excessive drop in voltage.

(28) Up to a certain point resistance of copper circuits change very little with increase or decrease of current flow. It is when the wires are loaded to a point where temperatures rise above normal that waste begins because with every increase in temperature resistance rises and power must be consumed to overcome it.

Rheostatic Resistance

Resistance already has been explained in general terms. We will now deal with it in connection with rheostatic resistance. (29) This is one way to reduce voltage to the precise pressure necessary to force a required number of amperes through resistance. (30) The rheostat transforms the pressure into heat, which is absorbed by the atmosphere immediately surrounding the resistance coils or grids. The power thus consumed represents waste if more pressure is broken down than is necessary to stabilize the arc.

The voltage of a circuit used in projection is presumed to be at a fixed pressure. It is and, for reasons we will explain, must be considerably higher than is required to force the requisite number of amperes through the arc resistance. This excess voltage must be reduced or "broken down" to the amount required to perform the work. This work is performed by a rheostat—an instrument composed of several resistance elements connected in series with each other, mounted on a frame from which it is thoroughly insulated and the whole encased in a suitable sheet metal cover, perforated thoroughly to provide means of ventilation.

The supply voltage may be almost anything from 80 to 250 volts, though ordinarily, when taken from power lines, it is either 110 or 220 volts. Amperage requirements on the other hand vary widely, depending upon the kind of arc employed and the amount of light required. It may be anything between 12 and 125 amperes and higher in some cases.

Let it be understood that, given a certain resistance, the higher the electrical pressure (voltage), the greater the number of amperes will be forced through. Conversely, the lower the pressure (voltage) the less the current flow will be.

(31) A projector arc light will not operate efficiently unless the supply voltage or pressure is considerably higher than that required to force the requisite amperage through the arc. A steady arc cannot be maintained with insufficient voltage. The arc will flutter. (32) Experience has shown that in order to secure arc stability at least 20 to 25 volts must be broken down. (33) This power dissipation is necessary to obtain the proper results.

(34) If, however, more voltage is broken down than is required to stabilize the light source, wasted power may be saved by the installation of a motor generator set, though this is not always profitable. For example: if the current is d. c. and the voltage 110, and if the voltage drop across the arc is 55, and if we break down 15 volts in the rheostat to attain arc stability, we will require altogether 70 volts supply pressure. If we subtract 70 from 110 we have 40 volts of waste power: we have only to multiply 40 by the amperage to ascertain the wattage loss; further multiply the result by the number of hours of operation per day and that by the price per watt hour, and we arrive at the cost of the power waste for each day of operation. With this we can estimate the saving achieved by the installation of a motor generator set. Any appreciable saving would be doubtful unless the current cost is high and the hours of daily operation long.

On the other hand, if the voltage supply is 220 (the arc stability breakdown remaining the same, as of course it would), we then would have a waste of 220 — 70 = 150 volts times the amperage, which under almost any possible circumstances would demand the installation of a motor generator set. In this case a motor generator would supply approximately 80 volts, eliminating the enormous waste.

(35) Waste may be defined roughly as all power delivered to a projector circuit in excess of 80 volts. We except the case of a 110 volt d. c. supply since here it would cost usually as much or more to eliminate it. We except also those situations where the stability requirement is somewhat below or in excess of 80 volts.

Resistance Elements

In breaking down voltage in the rheostat the power is transformed into heat. Hence the material used in the rheostat must be able to withstand high temperatures, though (36) such temperatures should never exceed a very dull red when viewed in a dark room.

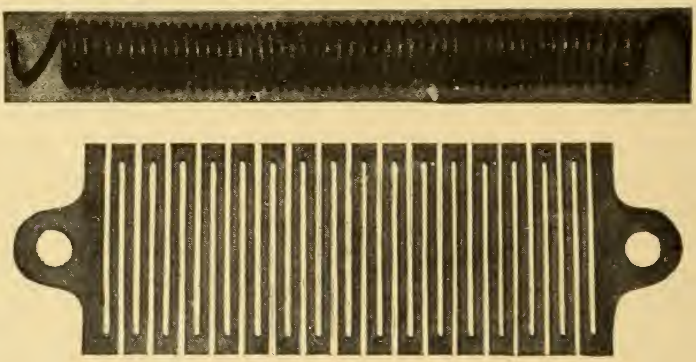


Figure 9

(37) Certain wires, known as "resistance wires," are wound into coils, each spiral separated approximately ⅛ inch from adjoining spirals; a number of such coils connected in series with each other constitute one type of rheostat. Iron of a certain grade cast into a "grid" and several of these grids connected into series with each other, is another popular rheostat element. The coil and grid types are illustrated in Fig. 9.

(38) These coils or grids are mounted upon a suitable metallic frame from which they are thoroughly insulated, usually by mica. Though details vary, the coil or grid is

insulated from the frame essentially as shown in Fig. 10. A is the rheostat frame, B is the holding bolt, CC are coil ends and the shaded portions are mica insulators.

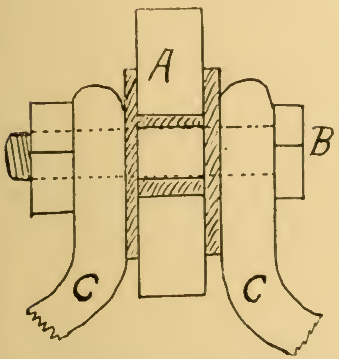


FIGURE 10

In reassembling coils or grids be very sure this insulation is complete so that there is no possible electrical contact between the frame or the casing and the resistance elements.

There are many forms of rheostat, but they all do exactly the same thing in various ways. (39) Since each inch of such a coil or grid of given diameter or cross section offers a certain amount of resistance to current flow, which requires voltage consumption (break-down) to force the current through, naturally the longer the path the current must travel through coils or grids the greater will be the total resistance, and consequently the greater the amount of voltage consumed.

Examining the grid, Fig. 9, it is seen that it is equivalent to a long cast iron wire. The coil shown in the same figure will be stretched somewhat when mounted, so that its spirals will be separated.

The resistance per unit length of grid or coil is known exactly; also known is the amount of resistance which will meet the passage of any definite number of amperes under an initial pressure. Therefore it requires only a very simple calculation to determine the coil or grid length required to pass any desired number of amperes taken from a 110, 220, or other voltage circuit.

(40) A rheostat will deliver an appreciably higher amperage when cold than after it has become hot. This is not a serious consideration in the small rheostats used in projection, but it is a serious objection in very large ones.

(41) The advantages and disadvantages of the grid

type as compared with wire coil rheostats are outlined below:

Advantages

(1) Grids are not so likely to sag and thus short circuit some of their elements, or become grounded to the casing as are coils. (2) Grids last longer than coils under the same conditions of service. (3) Grids are better able to withstand high temperatures than are coils. (4) Grids deteriorate very slowly.

Disadvantages

(1) A grid rheostat is much heavier than wire coil one of equal capacity. (2) Grids may be broken by a heavy jar. (3) Grids are more difficult to replace than are coils. (4) Temperature coefficient low and less fixed than that of the wire coil, hence grid somewhat less reliable as to stability in current delivery.

Inspection

(42) Resistances should be inspected carefully once each week and they should have a thorough examination on the first of each month. (43) As metal oxidizes under heat, wires should be removed from the binding posts each week and both wires and posts cleaned thoroughly with crocus cloth or 00 candpaper, preferably with sandpaper. They may look clean, but an almost invisible, high resistance scale forms nevertheless. Inspection once each week is based upon many hours of use each day. When there are only two shows a day examination once in two weeks is sufficient, but the thirty day inspection requirement holds good everywhere. This is especially important where rheostats are working at capacity or above.

Location of Rheostats

(44) Rheostats generate high temperatures. (45) Therefore they must not be located near inflammable material. (46) They should never be located in the main projection room in warm climates because of their heat-producing powers. They should have a vent outlet to open air.

(47) Under no circumstances should they be located at the floor level of a projection room, because of possible contact with film and because such location would tend to add to the heat of the room.

Extra Resistance

(48) Should a rheostat be somewhat lacking in amperage capacity, it is an easy matter to cut out one coil or grid by loosening the inside connection of a coil and clamping the circuit wire under it instead of connecting it to the binding post—provided such cut-out does not raise the temperature of the remaining coils or grids beyond the safety limit. If, on the other hand, too much amperage is supplied, an extra coil may be mounted on porcelain insulators attached to a non-inflammable support, with the circuit wire connected to one end and the other to the rheostat binding post. This is illustrated

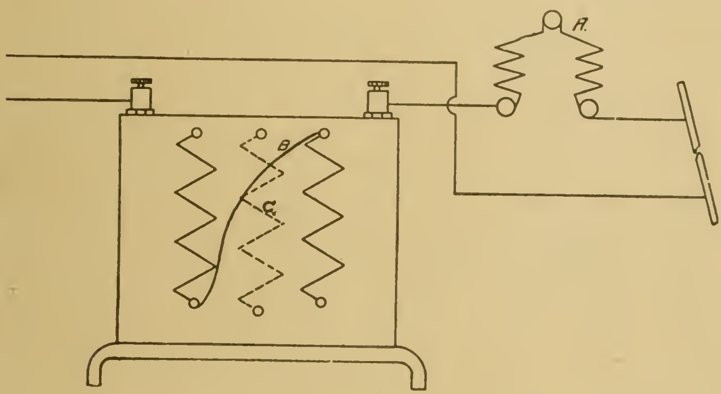


Figure 11

in Fig. 11, in which wire B shows how a defective coil C may be cut out temporarily. Also, at A, how additional resistance may be connected into series.

Rheostat Connections

(49) Rheostats may be connected in series or in parallel, the series type of connection being shown in Fig. 6, and the parallel (also termed "multiple") in Fig. 7. (50) In the series connection the current must pass through the entire length of the resistance elements of both rheostats, hence the total resistance (in two 2-ohm rheostats) would be 4 ohms.

The parallel connection permits all rheostats to deliver to the arc their full normal amperage capacity, but the voltage is neither raised or lowered in any degree. (51) If each rheostat has a voltage capacity not less than that of the circuit supplying it, two or more rheostats of unequal amperage capacity may be connected either in parallel or series. If the combined resistance of two rheostats is sufficient to oppose the line voltage without overloading the coils or grids, then two or more rheostats of unequal voltage capacity may be connected in series.

Any number of rheostats of different type, but each of voltage capacity at least equal to that of the supply circuit, may be connected either in series or parallel. For example, a 15 ampere, a 25 ampere and a 50 ampere 110 volt, or a 15 ampere 110 volt, a 25 ampere 220 volt and a 50 ampere 110 volt rheostat may be connected in parallel (multiple) on a 110 volt supply circuit. The current delivered would equal the total capacity of all the rheostats thus connected, but the 220 volt rheostat would deliver approximately but half the current it would when working on 220 volt lines. The three 110 volt rheostats would deliver 15 plus 25 plus 50 amperes. A 220 volt rheostat may be used on 100 volts (but a 110 volt rheostat may not be connected to a 220 volt circuit) though the amperage delivery would be very small. In the first case the amperage would be far less than the capacity of the instrument. In the second case the resistance element would quickly burn itself out.

A. C. and D. C. Rheostats

(52) No rheostat made today is specifically either a. c. or d. c. Any rheostat of proper voltage capacity may be used either on a d. c. or an a. c. circuit. (53) The only difference is that a wire coil rheostat will deliver a little more current on d. c. than on a. c. because on a. c. the coils set up an inductive effect commonly termed "magnetic kick," which adds to the total resistance.

Use on A. C. Bad Practice

(54) It is poor practice to use rheostatic resistance to control an a. c. light source. The proper instrument is a transformer. The waste is far less, the general results better and a rheostat on a. c. is apt to be noisy because of the inductive effect previously mentioned.

Adjustable Rheostats

(55) Rheostats may be had with fixed resistance, or with resistance that may be adjusted, within certain fixed limits, from time to time. Adjustable resistance is diagrammatically illustrated in Fig. 12, showing two binding posts, with certain resistance elements so connected that all or only a part may be used.

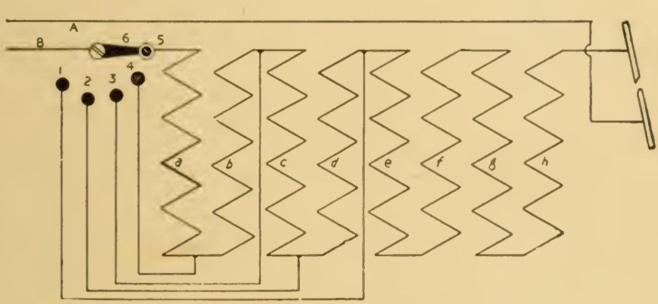


Figure 12

(56) A is one circuit wire and B the other. Wire B connects to the arc through lever 6 and contacts 1, 2, 3, 4 and 5 upon any of which the outer end of lever 6 may rest. It now rests on contact 5; hence it is evident that current must pass through all the resistance coils or grids. If it be moved to 4, coil A will be cut out; if moved to 3, coils A and B will be eliminated and so on, until only the "fixed resistance" will be in use. That is all there is to the adjustable rheostat. They all operate on the same general principle, though there are several variations in the manner in which the amount of resistance may be changed.

Calculating Resistances

In practice one orders a rheostat to deliver approximately the amperage required; or if some odd number of amperes is desired for which there is no stock rheostat available, he may order two of different capacities and connect them in series or parallel. In that way almost any amperage capacity may be built up.

(57) It is easy to calculate any resistance required in ohms. Suppose we have a 110 volt supply and propose using 60 amperes of current. Ohm's law tells us that voltage divided by amperes equals ohms. We know a 60 amp. arc operates at approximately 55 volts, hence 110 — 55 (representing voltage drop of arc) = 55, and 55 ÷ 60 = .916 + ohms required in rheostat. In other words, first subtract the voltage drop across the arc from the line voltage and divide the remainder by the desired amperage. Result will be the amount of resistance required, expressed in ohms.

Heat

A resistance coil or grid will function under any degree of heat that will not fuse it. (58) However, excessive temperatures cause rapid deterioration and lower their length of life. (59) Moreover, overloading resistance elements may at any time set up heat sufficient to fuse the metal, and thus stop all current flow.

(60) The maximum permissible resistance coil or grid temperature is 900° Fahr. This temperature will make the metal just visible in a dark room.

A dull red in daylight is approximately 1,300 degrees Fahr. At such a temperature resistance metal will not last long. Even 900 Fahr. is too high. Five hundred degrees Fahr. is as high as resistance really should be permitted to operate. Such a limit will greatly prolong the life of the coils or grids. (61) In practice if the metal is visible in a dark room the amperage should be cut down until the metal is invisible in total darkness. This can be done easily if it is an adjustable rheostat. If it is not, then you must either install an additional coil or coils, as in Fig. 11, or else get a rheostat of the required capacity, so that the amperage will not overheat the coils or grids.

(62) It is more efficient to work your rheostats below rather than above capacity. The general results will be better and the rheostats will last twice, or more than twice as long.

Testing for Ground

(63) If a test lamp is used to test for a ground between resistance elements and the rheostat casing, connect one test lamp lead to opposite polarity of the one leading to the rheostat; leave current switched on but turn off the light source. Touch the casing or metal frame with the end of the other test lamp wire. If the lamp lights or there is a spark when you remove the wire, then there is a live connection between the rheostat frame and the resistance elements. If the lamp burns brightly there is a heavy ground. If it burns but dimly or not at all, if a spark is emitted when the connection is broken, then the leak has high resistance. If the lamp does not light nor spark, then there is no "ground."

Testing for Grounded Coil or Grid

Testing for grounded coil or grid is a tedious job. First, remove the casing, then do whatever may be necessary to release the first coil or grid. It varies with different types of rheostat, but there should be little difficulty in finding the right way to do it.

Remove the first coil or grid and test with a magneto and bell. A battery and bell may be used instead of the magneto. A better method is to apply a test lamp after energizing the partly disassembled rheostat with voltage. If the ground still exists—the bell rings or the lamp lights—remove successive grids or coils until the test shows up clear. Obviously the previous element is at fault and repairs should be made at that point. In reassembling the rheostat be careful to get all coils or grids thoroughly insulated from the frame.

Fig. 13 is the diagrammatic representation of a rheostat—A B C D etc., being either coils or grids. At X coil or grid, E is grounded to the frame at point Z. According to the explanation just given, it would be necessary to remove coils A B C D and E, whereupon the rest of the resistance elements would test clear. It is then only necessary to find the insulation flaw at Z, make the repair, and reassemble.

If a battery or magneto is used, first disconnect the circuit wires and then touch the binding posts, one with each test wire. If the bell rings it shows the circuit

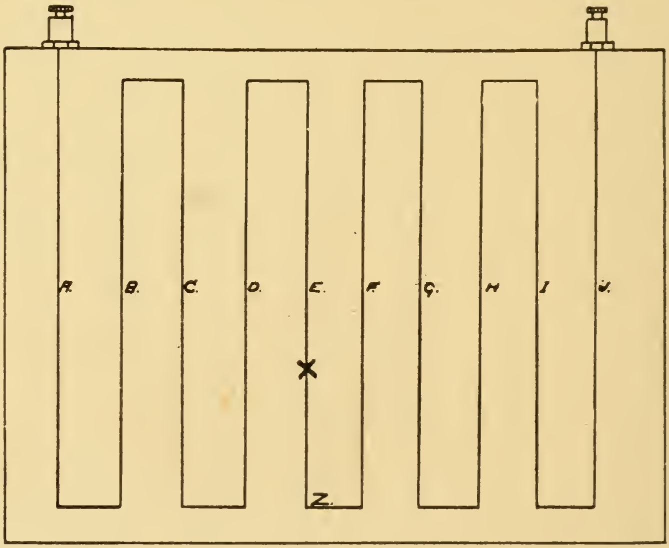


Figure 13

through the rheostat is complete. No wire or grid is broken or burned off.

However, this does not prove there is nothing wrong. In a wire coil rheostat, two coils often sag together, eliminating some of the resistance but not breaking the circuit. This trouble may manifest itself by an overheating of the coils. If not, it can be located by careful examination.

Insulating Rheostats

It is best to set your rheostats on insulating, fireproof material. Asbestos millboard, slate or marble is excellent. Such insulation is a protection against slow current leaks should a ground occur between rheostat frame and resistance elements.

Ballast Resistance

(64) Ballast resistance—or its equivalent in the form of impedance when a transformer is used—is necessary to insure the steady operation of an electric arc because an arc between carbons has what is called a negative temperature characteristic. (65) The term "negative temperature characteristic" means that the voltage drop through the arc stream of an arc of uniform length decreases with increasing temperature.

(66) If the arc is connected directly to a constant voltage circuit, with no resistance or impedance in series therewith, the voltage drop in the arc stream decreases as the temperature rises, which of course has the direct effect of permitting more current to flow. This in turn creates still higher temperature, resulting in a further voltage drop in the arc stream. This condition quickly leads to an unstable arc, and stability in a projection arc is of paramount importance.

(67) The voltage drop across a ballast resistance—or its equivalent in transformer impedance—is equal to the product of the resistance and current flowing through it. (68) Therefore the voltage absorbed by the resistance increases with increasing current flow and decreases with decreasing current flow.

(69) When resistance or impedance is connected in series with an arc, it serves as a ballast or stabilizer of the current flow because the effect on voltage by changes in current flow are opposite to those in the arc stream. The drop in voltage in the arc stream which follows increase in temperature permits some increase in current, but this, in its turn, causes more of the line voltage to be absorbed in the ballast resistance, and thus reduces the voltage applied to the arc. Thus the increase of current is definitely limited or retarded, and consequently the action of the arc is stabilized.

(70) As the carbons burn away, increasing the arc length, the voltage drop in the arc stream is increased, tending to reduce current flow. This in turn operates to decrease the voltage drop through the ballast resistance, and thus the voltage applied to the arc is raised to meet the requirement of an increased arc length and again a stabilizing effect is set up.

To illustrate this action by specific example, assume a 30 ampere, 55 volt arc operating from a 115 volt circuit. A ballast resistance of two ohms will absorb the difference of (110 — 55) 55 volts between the arc and line voltage. Should the current rise above 30 amperes, or fall below, the voltage absorbed in the ballast resistance will rise or fall proportionately, raising or lowering the voltage applied to the arc, as previously explained. These changes are shown in the following table:

TABLE I.

Arc Current Amperes	Change in Arc Current	Volts Absorbed in 2 Ohm Ballast	Volts Applied at Arc	% Change in Volts at Arc
		Rising Arc Current		
31	3.3%	62	53	3.6
32	6.7	64	51	7.3
35	16.7	70	45	18.2
		Falling Arc Current		
29	3.3%	58	57	3.6
28	6.7	56	59	7.3
25	16.7	50	65	18.2

It is evident from this table that the effect of the ballast resistance is to restore the arc condition to normal and thereby maintain stable operation.

GROUNDS

1. What two types of grounds are there?
2. Why are permanent grounds employed?
3. Is current leakage set up by grounding one wire of a circuit?
4. Do earth grounds offer variable resistance?
5. May a positive and negative have earth ground with but little current flow?
6. May a ground through something other than earth offer sufficient resistance to prevent current leakage?
7. If one polarity grounds to the lamp frame and the other does not, what is the effect?
8. How may slight current leakage sometimes be set up?
9. With what may grounds be tested?
10. If the test lamp, bell and battery or magneto is connected across a ground, will the lamp light or the bell ring?
11. Is failure of lamp to light or bell to ring conclusive proof that there is no ground?
12. Why must all high resistance grounds be detected?
13. Why will a test lamp not light when connected across an Edison 3-wire neutral ground?
14. What is the surest way of testing an Edison 3-wire circuit in which the neutral is involved?
15. Should projection rooms be equipped with a magneto?
16. Describe a 110-220 volt test lamp.
17. How many batteries (dry cells) should be used for testing, and how should they be connected?
18. Why is one dry cell insufficient for ground testing?
19. How would you proceed to test your arc lamp for ground?
20. How would you proceed to install a permanent test lamp?
21. What wire would you use if a ground to earth is suspected.
22. When testing for ground in your lamp, should permanent ground of both test lamp and projector be disconnected?
23. What various equipments should be grounded and why?
24. How often should equipments be tested for ground?

CHAPTER III.

GROUNDS: HOW TO TEST FOR THEM

(1) A "ground" may indicate one of two conditions: (a) A connection of one or both polarities to earth, with or without evidence of current leakage, or (b) a connection of polarities through an unsuspected path other than the earth, resulting in an unintended current flow.

(2) A ground may be intentional, as in an Edison 3-wire system, in which the neutral is permanently grounded in order to protect the conduit, etc., from being charged at high voltage, which is a dangerous condition. (3) The grounding of the neutral causes no current leakage unless one of the other wires becomes grounded to earth, and the path between the two grounds —because of low resistance—permits the voltage to force current through.

Effect of Ground Resistance

(4) Every ground through earth offers resistance, otherwise it would be a short circuit. The points at which opposite polarities contact earth may be close together, and yet the earth will offer little resistance, especially when it is wet. In such a case there would be heavy current leakage. (5) The points of contact may be relatively near, but the resistance so great that little or no current will flow through. The likelihood of high resistance in the ground is greater with the increasing distance between the points of contact with the earth.

(6) Ground through something other than earth is much the same in effect, except that the reasons for low or high resistance are different. (7) Take for example, the lamphouse and its electrical circuit. A worn spot in the insulation or a loose strand in a positive wire

contacts the metal of the lamp frame or lamphouse. The negative wire has no such contact, hence the only effect is to charge metal with EMF—and there may be current loss through the permanent ground of the opposite wire, the amount of current flowing through the ground varying with the resistance set up by the earth at that particular point. The permanent ground of the projector frame is not considered.

(8) Sometimes opposite polarities have no contact, earth or otherwise, but carbon dust may settle across the carbon jaw, thus setting up a slight current leak. Or opposite polarity may contact metal, but if the contact is spotty because of dirt or other interfering element, the resistance will be high and little current will pass through.

If the ground has very low resistance it is called a "short circuit."

Testing For Grounds

(9) Testing for grounds is a very simple matter, once the action of current is understood. If one polarity is grounded to your lamp or lamphouse (we, for the moment, disregard the Edison 3-wire system) and you touch one wire of a test lamp, or of a bell and battery to the lamphouse metal or lamp metal, and the other to a charged wire of opposite polarity, (10) it is evident current will flow through the ground contact and light the lamp or ring the bell, as the case may be.

(11) In making tests with a test lamp or bell and battery, the fact that the bell does not ring or the lamp does not light is not conclusive proof there is no ground. There may be a ground of such high resistance that there is insufficient current to ring the bell or light the lamp. In that case hold one wire in contact with a live wire of opposite polarity and with the other make and break contact with the metal of the lamp or lamphouse, watching closely for a spark. This test should be made in darkness. (12) It is very important that all high resistance grounds be detected to prevent small but constant current loss.

(13) If the system is an Edison 3-wire, a test lamp will not show light from neutral to ground because the neutral is already permanently grounded.

(14) When using an Edison 3-wire system it is safest to disconnect the wires by opening a switch, and test with either a battery and bell or with a magneto.

(15) A magneto is an excellent investment, because it generates high voltage and will immediately detect light grounds that would not be detected by either a battery and bell or a test lamp except by very careful work.

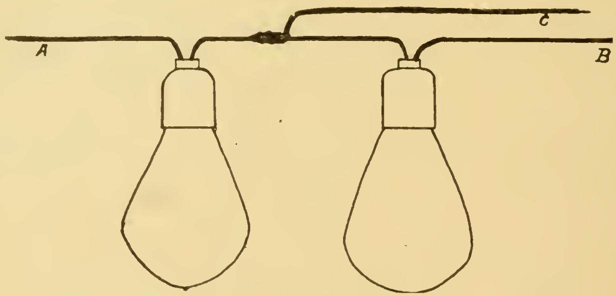


FIGURE 14

(16) Fig. 14 illustrates a convenient test lamp connection for a 110-220 volt test; one lamp and wires A C for the 110 volt test.

(17) To test with battery and bell, or with battery without any bell, first disconnect the mechanism from the circuit, either by opening a switch or by disconnecting the circuit wires. Next, connect two or three dry cells in series, with test wires leading from the outer poles of the battery thus formed to the parts to be tested. (18) Voltage from a single battery cell is too low to have value except in a very low resistance ground.

It is now only necessary to contact the two test wires across the suspected parts. If there is a ground, either the bell will ring or there will be a spark when the connection is broken. We prefer the spark test, for reasons already explained. (19) If an arc lamp is being tested, contact one carbon arm on "live" side of insulation, and the lamp frame with the other wire. If there is no bell action or spark, all is well—so far as the low voltage of a battery will determine. A magneto is a better testing instrument. It detects not only an actual ground, but also discovers weaknesses in the insulation.

To test with test lamp, the same procedure is followed, except that the switch must be closed and the circuit thus charged with line voltage.

Permanent Test Lamp

(20) It is well to install a test lamp permanently connected to ground. To do this it is only necessary to install a socket (two of them if a 3-wire test outfit as illustrated in Fig. 14 is required) on the projection room wall at any convenient place, connecting one side of it to ground by means of a water pipe, to which clean, firm, metallic contact must be made. To the other side connect two test wires long enough to reach the parts to be tested. The permanent ground wire should have a switch so that it may be disconnected. A trouble-lamp retrieving reel is excellent for these wires. It may be installed on the ceiling beside the test lamps. One reel will handle both wires, which may be ordinary lamp cord.

(21) If a ground to earth is suspected, use one wire —the one opposite to the permanent ground wire. (22) If you wish to test for the kind of ground that means a limited "short" between parts of an arc lamp, pull the switch, disconnecting the earth ground (disconnect projector ground wire) and use both wires on suspected parts.

Grounding for Projector

(23) The projector lamphouse and stand should always be connected to ground by means of a "ground wire," which is a wire connecting the part with permanent grounds, such as water pipes, the metal work of the projection room, frame work, etc. This is to avoid shocks to the men at work. The motor generator frame and stand of spots, etc., should be similarly grounded.

(24) Projectionists should test their apparatus, par-

ticularly the arc lamps, every day. If the permanent ground lamp is installed it involves little work or trouble. Often current bills are large because of small leaks that exist unsuspected in untested apparatus.

ELECTRICAL CONDUCTORS

1. What properties are considered of basic importance in conductors?
2. What two widely different purposes do conductors employed in projection work serve?
3. Why was copper selected as standard for electrical conductors?

Wire Capacities, page 62

4. What authority fixes the capacity limits of electrical conductors?
5. What would happen were the specified capacity limits exceeded?
6. What standard wire gauge is used to measure wire diameters?
7. May varnished cloth insulation be used on any diameter of wire?
8. May anything less than No. 14 wire be used for inside work?
9. What kind of wires does table No. 3 cover?
10. For what purpose may table No. 4 be used?
11. Using table No. 4 how would you calculate the resistance of a copper circuit?
12. Is resistance for any current flow up to the rated capacity of a wire practically the same?

Mil Foot Standard, page 64

13. Upon what is the calculation of resistance based?
14. What is a "mil foot" of resistance?
15. What is the resistance of one mil foot of commercial copper at 75 degrees Fahrenheit?
16. How is resistance of a circuit calculated?
17. Quote the rule for calculating resistance of circuits.
18. Does age affect resistance of copper conductors that have not been subjected to overload?

Calculating Voltage Drop, page 66

19. How do you calculate voltage drop?

How to Measure Wires, page 67

20. In what form is the cross section area of wires expressed?
21. To what is the area of cross section of round wires equal?
22. How may current capacity of any round commercial copper wire be determined?
23. Is it the slots or round holes of B. & S. gauges that are used for measuring wires?
24. Explain markings on these gauges.

Insulation, page 68

25. What is the purpose of insulation?
26. Is there any known substance through which a substantial amount of current cannot be forced if voltage is sufficiently high?
27. Name some of the substances that are used as insulators for ordinary commercial voltage.
28. Of what does rubber covered wire insulation consist?
29. Is rubber insulation easily injured by heat or oil?
30. Why are rubber covered wires limited to a lower amperage capacity than wires having other insulations?
31. Is there a fireproof insulation for inside work?
32. Name specifications for wires to be installed in conduit.

Wire Systems, page 70

33. Resolved to fundamentals, do all systems constitute 2-wire circuits?
34. May circuits be attached to a wire system at any point charged with voltage proper for the equipment to be operated?
35. Upon what basic principle do 3-wire systems depend for operation?
36. If two 110 volt generators are properly connected to a 3-wire system, what voltage will the outside wires have?

37. Will the neutral wire be positive or negative?
38. If 110 volt lamps or motors be connected to each side of a 110-220 volt 3-wire circuit, will they operate at 110 or 220 volts?
39. If lamps or motors are attached to each side of a 3-wire circuit, the total, and the combined amperage capacity of those attached to each side being unequal, what will happen?
40. Explain the current action illustrated in Fig. 17.
41. What is the correct designation of the two outside wires?
42. What is the effect of an unbalanced load on the generators supplying a 3-wire system?
43. Were the load equally balanced would there be any need for a fuse in the neutral wire?
44. Why should projector lamps be connected to opposite sides of a 3-wire circuit?
45. Why do power plants of small capacity insist upon the connection of both projector light sources to the outside wires of a 3-wire system?
46. Why is such a connection unobjectionable if the power is taken through transformers, but highly objectionable if the voltage is reduced by rheostatic resistance?
47. Explain the problem set up by Fig. 18 and the accompanying text.
48. How may the unbalance of the load be measured?
49. How may wire sizes of a 3-wire circuit be calculated?

SWITCHES, PAGE 75

50. What is meant by a single-pole, single-throw (S.P.D.T.) switch?
51. What is a single-pole, double-throw switch?
52. Describe the several types of single-throw switches.
53. Is it of vital importance that switches be conveniently located?
54. In installing knife switches, what should be avoided? How should the blade or blades be placed?
55. How often should knife blade switches be inspected?
56. What faults should be looked for at inspection?
57. What is meant by an "inclosed switch" and why is it inclosed?
58. How should inclosed switches be connected?
59. Is it desirable to so connect all knife switches that the blades will not be charged when open?

60. Where should emergency switches never be located?
61. What precautions should be taken to prevent the possibility of opening of the emergency light control switch at the wrong time?
62. What should be done before installing a single-pole switch?
63. Does the National Electric Code require that all switches be marked with specified dimensions?
64. May a switch be used for a higher voltage or amperage than its rating?
65. Should all circuit switches and fuses be inclosed in cabinets?

Switchboards, page 80

66. What are the flat copper bars on switchboards called?
67. How are connections between bus bars located?

Fuses, page 81

68. Do electric conductors carry fixed amperage?
69. What may cause a rise in voltage, with consequent rise in amperage, thus endangering a circuit and its attached equipment unless protection is afforded by fuses?
70. What is a "fuse"?
71. Are fuses installed in both wires of an electric circuit?
72. In what manner do fuses protect a circuit?
73. When a fuse "blows" (melts), what must be done before a new fuse is installed?
74. With current overload why does fuse temperature rise more rapidly than that of the circuit wires?
75. What various kinds and types of fuse may be installed in theatres?
76. Where and under what circumstances are link fuses permissible in theatres?
77. Describe the general construction of cartridge fuse elements.
78. Describe the plug fuse and its connections.
79. What is a "link" fuse?
80. What is meant by "boosting" a fuse?
81. What is the practical effect of boosting fuses?

Fusing Projection Room Circuits, page 87

82. What exception to fusing rules in general applies to projection light source circuits?

Fusing Motor Generator Circuits, page 87

83. Should fuses be installed on both primary and secondary of motor generator sets?
84. Should a good stock of fuses be kept on hand?
85. What may be used to protect a circuit temporarily when no proper fuse is available?
86. A fuse blows. A new one is installed, but immediately blows. What does that indicate?
87. Should a fuse blow and the new one installed also blow, but only after a lapse of time, what is indicated?
88. Why should all fuse contacts be inspected at periodic intervals?
89. How often should fuses on an 110 volt current be inspected?
90. Name the various points where fuses should be installed in theatres.
91. Should fuses not plainly marked with voltage and amperage capacity be rejected?
92. Describe a cheap, efficient home-made fuse tester.

Making Wire Splices, page 90

93. What should be done before attaching a wire to a binding post?
94. Describe method of soldering a wire to a binding post.
95. What care must be exercised in removing insulation from a wire end?
96. Should the wires be cleaned thoroughly?
97. Is there danger of heating the wire too much?
98. How should a splice be insulated when completed?
99. Must a good, mechanically tight joint be made before soldering?
100. Describe a good soldering solution.

CHAPTER IV.

ELECTRICAL CONDUCTORS

(1) Electric conductors usually are selected with certain basic ends in view, namely: (a) degree of conductivity, (b) tensile strength, (c) ductility, (d) freedom from corrosion, and (e) low cost.

(2) Conductors employed in projection have two widely different purposes. They are meant to convey current with the least possible resistance, or to offer comparatively high, non-fluctuating resistance.

(3) In the first case copper is employed almost exclusively for the reason that it best combines the basic requirements of low cost, low resistance, tensile strength, ductility and freedom from corrosion.

In the second case a metal that offers high resistance is used, since rheostatic resistance forms an integral part of some projection circuits.

Wire Capacities

(4) Wire capacities are fixed by the National Board of Fire Underwriters, (5) whose instructions it is dangerous to ignore or violate, since such violation would automatically void all insurance on a building, or even prevent the owner from obtaining insurance. The Board of Underwriters has adopted the wire capacity rating recommended by the American Institute of Electrical Engineers and it is now part of the National Electrical Code. Table No. 2 on page 63 gives the allowable continuous current-carrying capacities of copper wires and cables of 98% conductivity and (6) is based upon wire diameters measured with a Brown & Sharpe wire gauge. It takes in wires up to 0000 size only, which serves all projection room requirements.

(7) Varnished cloth-insulated wires, smaller than No. 6, may be used only by special permission.

(8) The Board of Fire Underwriters does not recognize anything less than number 18 wire. Nothing less than No. 14 may be used for interior circuit wires.

(9) Table No. 3 gives details of standard wire, not including what is known as asbestos-covered, used for connecting projector table switch with the lamp. (10) Table No. 4 may be used for calculating the resistance of any copper circuit the exact length of which is known.

TABLE NO. 2

No. Gage	Diameter of Solid Wires in Mils	Area in Circular Mils	Rubber Insulation, Amperes	Varnished Cambric Insulation, Amperes	Other* Insulation. Amperes
18	40.3	1,624	3		6
16	50.8	2,583	6		10
14	64.1	4,107	15	18	20
12	80.8	6,530	20	25	30
10	101.9	10,380	25	30	35
8	128.5	16,510	35	40	50
6	162.0	26,250	50	60	70
5	181.9	33,100	55	65	80
4	204.3	41,740	70	85	90
3	229.4	52,630	80	95	100
2	257.6	66,370	90	110	125
1	289.3	83,690	100	120	150
0	325.0	105,500	125	150	200
00	364.8	133,100	150	180	225
000	409.6	167,800	175	210	275
		200,000	200	240	300
0000	460.0	211,600	225	270	325

*For insulated aluminum allow 84 percent of Table No. 1 capacity rating.

(11) In using Table No. 4, suppose we find the projection room feed circuit to be fifty feet long. That would be a total of 100 feet of wire, since there are two wires in a circuit. The wires, measured with a B & S gauge, prove to be No. 5. Examining Table No. 4 we find No. 5 copper to have .3174 of an ohm resistance per each 1,000 feet of length, or .003173 of an ohm per foot. The circuit has 100 feet of wire, hence the total resistance of the whole circuit will be 100 × .0003174 = .03174 of an ohm.

Tables Nos. 2 and 3 give correct data up to capacity of the wires—in other words until the load becomes sufficiently heavy so that to add to it would raise the wire temperature above the approved maximum.

(12) Resistance for any volume of current up to the

rated capacity of a wire is, for all practical purposes, the same—the rise in temperature is too slight to be a factor.

Mil Foot Standard

(13) Calculation of resistance in electrical conductors is based upon what is known as the "mil foot," (14) which is the resistance of a wire of the same characteristics as the one to be calculated, and which is one mil (1/1000 of an inch) in diameter and one foot long.

TABLE NO. 3
STANDARDIZED STRANDING

Strands		Cable		Allowable Carrying Capacities in Amperes		
No. of Strands Mils Dia.	G & S. Gauge No.	Area in Cir. Mils	Outside Dia. over Copper	Table A Rubber Insulation	Table B Varnished Cloth Insulation	Table C Other Insulation
7/ 25	22	4,490	.075	15	18	20
7/ 32	20	7,150	.096	20	25	25
7/ 40	18	11,370	.120	25	30	35
7/ 51	16	18,080	.153	35	40	50
7/ 64	14	28,740	.192	50	60	70
7/ 81	12	45,710	.253	70	85	90
7/ 91	11	58,000	.273	80	95	110
7/102	10	72,680	.306	90	110	130
19/ 64	14	78,030	.320	100	120	150
19/ 72	13	98,380	.360	125	150	175
19/ 81	12	124,900	.405	150	180	210
19/ 91	11	157,300	.455	175	210	250
19/107	*	217,500	.540	225	270	325
19/114	9	248,700	.570	250	300	350
37/ 91	11	306,400	.637	275	330	400
37/ 97	*	347,500	.679	300	360	450
37/102	10	381,200	.714	325	390	500
37/116	*	484,300	.798	400	480	600
61/102	10	633,300	.918	475	565	700
61/107	*	698,000	.963	500	600	750
61/114	9	788,500	1.030	550	660	825
61/121	*	893,100	1.090	600	720	900
61/128	8	1,007,000	1.150	650	780	1000
91/114	9	1,191,000	1.250	725	870	1125
91/128	8	1,502,000	1.410	850	1020	1350
127/114	9	1,660,000	1.480	900	1100	1460
127/128	8	2,097,000	1.660	1100	1300	1700

*These individual strands are odd sizes not listed in the American or B. & S. Wire Tables.

(15) The resistance of one mil foot wire made of commercial copper is 10.5 ohms at normal temperature of 75 degrees Fahrenheit.

Resistance of Copper Circuits

(16) In applying the mil foot standard we will assume a circuit to be of No. 6 wire and that it is 200 feet in length, having 400 feet of wire. If one foot of

wire of one mil cross-section area has a resistance of 10.5 ohms, then 400 feet will have 400 × 10.5 = 4200 ohms resistance. However, the resistance of a wire of given length decreases as its diameter increases. Table

TABLE NO. 4

RESISTANCE OF COPPER WIRE AT NORMAL TEMPERATURE

Am. Gauge, B. & S. No.	Resistance at 75° F., International Units			
	Ohms per 1000 Feet	Ohms per Mile	Feet per Ohm	Ohms per Lb.
0000	0.04964	0.2621	20147.	0.00007758
000	0.06261	0.3306	15972.	0.0001234
00	0.07894	0.4168	12668.	0.0001962
0	0.09945	0.5251	10055.	0.0003114
1	0.1255	0.6627	7968.	0.0004960
2	0.1583	0.8360	6316.	0.0007894
3	0.1966	1.054	5010.	0.001254
4	0.2516	1.329	3974.	0.001994
5	0.3174	1.676	3150.	0.003173
6	0.4002	2.113	2499.	0.005043
7	0.5044	2.663	1982.	0.008013
8	0.6361	3.358	1572.	0.01274
9	0.8026	4.238	1246.	0.02029
10	1.011	5.340	988.8	0.03220
11	1.277	6.743	783.1	0.05135
12	1.609	8.496	621.5	0.08154
13	2.026	10.70	493.6	0.1293
14	2.556	13.50	391.2	0.2058
15	3.221	17.01	310.4	0.3268
16	4.070	21.49	245.7	0.5216
17	5.118	27.02	195.4	0.8249
18	6.466	34.14	154.6	1.317
19	8.151	43.04	122.7	2.092
20	10.26	54.15	97.51	3.312
21	12.93	68.26	77.35	5.263
22	16.41	86.62	60.95	8.476
23	20.56	108.6	48.63	13.32
24	26.00	137.3	38.47	21.28
25	32.78	173.1	30.51	33.84
26	41.54	219.4	24.07	54.35
27	52.09	275.0	19.20	85.44
28	66.17	349.4	15.11	137.9
29	82.27	434.4	12.15	213.1
30	105.1	554.7	9.519	347.6
31	131.7	695.4	7.592	546.3
32	166.2	877.4	6.018	869.6
33	209.5	1106.	4.772	1383.
34	264.6	1397.	3.779	2205.
35	333.7	1762.	2.996	3507.
36	420.1	2218.	2.380	5558.
37	530.4	2801.	1.885	8860.
38	669.9	3537.	1.493	14131.
39	843.0	4451.	1.186	22378.
40	1065.	5625.	0.9387	35734.

No. 2 shows that a No. 6 wire is 162 mils in diameter and has a cross section area of 26,250 C. M. (circular mils). It follows that the resistance of our 400 feet of No. 6 wire would be equal to the resistance of 400 feet of 1-mil wire (4,200 ohms) divided by the cross-section area of the larger wire (26,250 mils) since the No. 6 wire would in effect be equal to 26,250 1-mil wires.

(17) Therefore, to ascertain the resistance offered by a circuit of commercial copper, multiply its length in feet by two. Multiply the result by 10.5 and divide by the cross section area of the wire in circular mils.

In calculating circuits it is customary to take double the mil-foot standard instead of twice the length of the circuit. Either way is correct. Both return identical results. Expressed as a formula the rule is this:

$$\frac{\textit{Twice the length of circuit in feet} \times 10.5}{\textit{Area of wire in circular mils}} = \textit{Resistance of circuit in ohms}$$

The rule is based upon the supposition that the temperature does not exceed 75 degrees Fahr. (24 degrees Centigrade). If the circuit is not overloaded, temperature may be disregarded. If this temperature is more than 75 degrees Fahr. it will tend to increase resistance.

(18) Age—several years of use—does not affect the resistance of electrical conductors appreciably unless they are worked above capacity or become overheated. An occasional slight rise in temperature above 75 degrees will do no permanent harm but one heavy over-heating will damage a conductor permanently, raising its resistance and weakening the copper.

Voltage Drop Calculations

Following are the formulas used by electrical engineers in calculating voltage drop. If projectionists use them intelligently they will save a great deal of electrical power. L stands for one-way length of circuit. A for cross sectional area of wire in circular mils. C for voltage drop in volts. E for voltage in circuit. I for current in amperes. R for resistance in ohms. P for voltage drop, expressed in percentage.

In these formulas we have doubled the mil-foot standard instead of doubling the length of the circuit.

Formula No. 1: $\frac{21 \times L}{A} = R.$

Formula No. 2: $e = L \times R$

Formula No. 3: $e = \frac{21 \times I \times L}{A}$

Formula No. 4: $A = \frac{21 \times I \times L}{e}$

Formula No. 5: When voltage drop is expressed in percentages, Formula No. 5 may be used to determine the wire cross-section area necessary to provide the required voltage drop:

$$\frac{2100 \times I \times L}{E \times P} = A \text{ or cross-section in circular mils.}$$

(19) Suppose a circuit is needed with a one-way length of 60 feet to carry 100 amperes with a 3 percent voltage drop, the voltage of the circuit being 110. Substituting figures in place of the letters we have

$$\frac{2100 \times 100 \times 60}{110 \times 3} = 38{,}181 \text{ circular mils.}$$

No. 5 wire being too small (see Table No. 2), we would have to employ No. 4, which would be a little too large and would not give quite the 3 percent drop.

Measuring Wires

(20) Cross-section area of wires is expressed in circular mils. For conductors other than round in form the square mil is used.

A circle 1/1000 of an inch in diameter is called a "circular mil," abbreviated to C.M. The cross-section area means C.M. area of the end of the wire. (21) Cross-section area of round wires is equal to the square of the wire diameter expressed in C.M. To square the diameter of a wire, multiply its diameter in circular mils by itself.

(22) The capacity of any round wire of commercial

copper may be ascertained by measuring its diameter in thousandths of an inch, multiplying the diameter by itself and comparing the result with Table No. 2, or by measuring with a B & S gauge and noting the mil diameter of the slot.

Wire Gauge

(23) In B & S gauges (shown in Fig. 15) the slots, not the round openings, are used for measuring wires. (24) Opposite each slot is the mil diameter of the wire

Figure 15

that fits it. On the opposite side is the number of the wire. Wires should fit the proper slot without binding.

Insulation

(25) Insulation is designed to prevent direct contact between wires having opposite polarity, or their contact with any object through which current may flow to opposite polarity, or their contact with any object providing an unintended path. Such electrical contact or path of conductivity may be supplied by direct contact between two wires of opposite polarity or by both coming into contact with a third wire or other object which

will conduct current, or by both wires coming into contact with damp ground.

Various materials offer varying resistance to the passage of current. (26) In fact, so far as is known there is no substance through which current cannot be forced if the voltage is high enough. There are, however, substances through which only minute current will flow unless the voltage be above, and in some cases far above, the voltage used for ordinary commercial work. Some of these substances are considered as insulating materials and are used as such. At the head of the list stand, in the order named, (27) glass, porcelain, mica and rubber.

Various natural substances such as marble, mica, slate and asbestos are excellent insulating materials for ordinary commercial voltages up to 220 volts. There are also many insulating compounds, their composition often being a trade secret. In practice such compounds are used to saturate cloth, or other material, which afterward are used in many forms for insulation purposes.

"R. C."

(28) The initial "RC" or R.C. stands for "rubber covered." Rubber covered wire is first coated with tin. It is then coated with either pure rubber or a rubber compound, over which is placed one or more protective coverings of cotton braid which has been impregnated with insulating compound. The tin coating is to prevent the sulphur present in rubber from attaching the copper.

(29) Rubber is a highly satisfactory insulation material but it is easily injured by heat or oil. Consequently under no circumstances should rubber covered wires be overloaded. Overloading—that is, increased temperature—hardens the rubber, renders it brittle and destroys its insulating value. (30) Because of this deficiency rubber-covered wires are rated lower in amperage than are wires of similar diameter and com-

position covered with weatherproof or fireproof insulation.

WEATHERPROOF INSULATION

There are several types of weatherproof insulation, but they are used chiefly for outdoor work. (31) A form of insulation known as "fireproof" is used for interior work where the air is warm and dry.

(32) Specifications for conduit insulation are as follows, taken bodily from the National Code:

"Conduit wire shall be of approved rubber-covered type (Types R, RD, etc.), or, if in a permanently dry location, may be of the varnished-cambric insulated type (Type VC). A double braid shall be provided for conductors larger than No. 8 and for all twin, twisted or multiple-conductor cables. Slow-burning insulation (Type SB wire) or asbestos covered wire (Type A) shall be used in permanently dry locations where the ambient temperature of the wire as installed, will exceed 120 deg. F. (49 deg. C.). With flexible metallic conduit in wet or damp places wires shall have lead coverings (Type RL). All wires of No. 6 or larger shall be stranded. There shall be no splice or tap within the conduit proper."

THE TWO-WIRE SYSTEM

(33) Fundamentally all circuits are of the 2-wire type. A 2-wire system is illustrated in Fig. 16. It con-

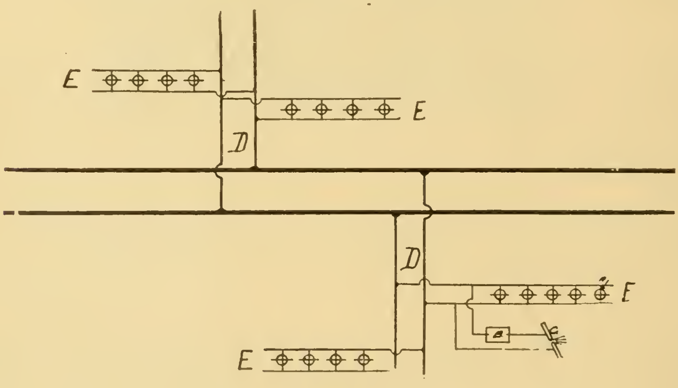


FIGURE 16

sists of two wires which form the mains from which current is distributed on auxiliary 2-wire circuits. These, in their turn, serve circuits within buildings as shown at EEEE, Fig. 16, which also shows a projection lamp taking current through rheostat B from a circuit attached to one of the house circuits. (34) When this system is charged with ordinary commercial voltage, we may draw circuits from the street mains at any point, or we may attach motors, lamps and other equipment to wires connected with the mains at any required point. The wires, switches, fuses, etc., must be large enough to carry the current without overload.

Three-Wire System

The 3-wire system is the most widely used for distribution of current for light, heat and power. It is diagrammatically illustrated in Fig. 17. (35) It is based on the principle that if two generators are connected in series—that is to say the positive pole of one is joined to the negative pole of the other—the voltage of the two generators will be added together, so that lines attached

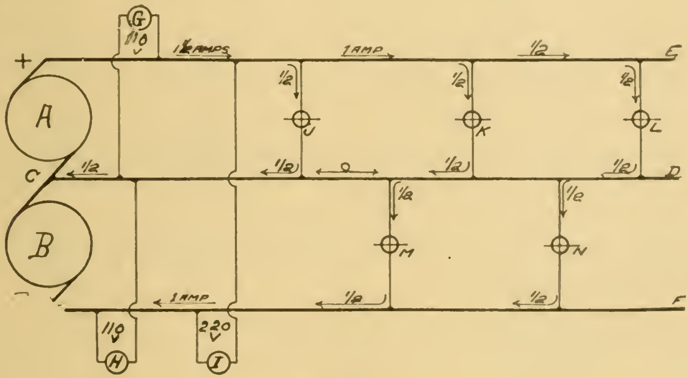


Figure 17

to the outer negative and the outer positive will be charged at double the voltage of each generator considered singly. Thus: (36) if two 110 volt generators are joined, the outside negative and positive would have a potential difference of 220 volts. (37) If we attach a third wire to the connection between the inner generator poles, C, Fig. 17, then that line (termed the "neutral" wire) will act as positive for one generator as if there were but one generator and negative for the other generator just as if the connection between the two machines were broken. There is this peculiarity: (38) if power-consuming devices are attached between either outside wire and the neutral wire, they will operate normally under 110 volts pressure. If the devices on either side of the neutral have equal capacity—use exactly the same amount of current—then they will work in series under 220 volts pressure and no current will flow either to or from the generators on the neutral wire.

(39) On the other hand, if the load on either side of the neutral wire is unequal, then the amount of the unbalanced load will flow back to or out from the generator on the "heavy" side, the direction of the flow depending upon whether the neutral is negative or positive to the generator connected to the "heavy" load.

(40) In Fig. 17 are three lamps, each using 0.5 of an ampere, connected between the upper outside wire and the neutral. Two lamps, each using 0.5 of an ampere, are connected between the lower outside wire and the neutral. We thus have a load balance of one ampere, with 0.5 of an ampere over. The surplus must therefore flow back to the upper generator over the neutral because it is negative to that generator. Under the newer interpretation it flows out, since we now consider current as flowing from negative to positive instead of from positive to negative.

G and H are 110 volt voltmeters. 220 volt voltmeter I measures the voltage between the two outside wires. (41) The outside wires are known as the "true negative" and "true positive." (42) The effect of an unbalanced load is to force the one generator to carry more than the other. The intention of course is to have a perfectly balanced load at all times though it is seldom attained. (43) Were it possible always to maintain an exactly balanced load there would be no need for a fuse on the neutral wire, since it would carry no current at all between the last piece of equipment and the generators.

(44) Power companies object to both projectors being connected to one side of a 3-wire system because that

means a very heavy intermittent unbalance of the load. If the projection room is supplied by a 3-wire circuit the projector lamps should always be connected to opposite sides of the circuit, especially where the power plant is a small one.

(45) Officials of a small plant will, if they know their business, not only object to two projector arc lamps being connected to the same side, but may insist that they be connected to the outside wires thus being fed with 220 volt current.

(46) If a. c. is used at the arc and power is taken through transformers there is little objection to connecting to outside wires. The total energy taken from the lines would be practically the same as though 110 volt transformers were used on each side. If current is taken through rheostats, the power company would

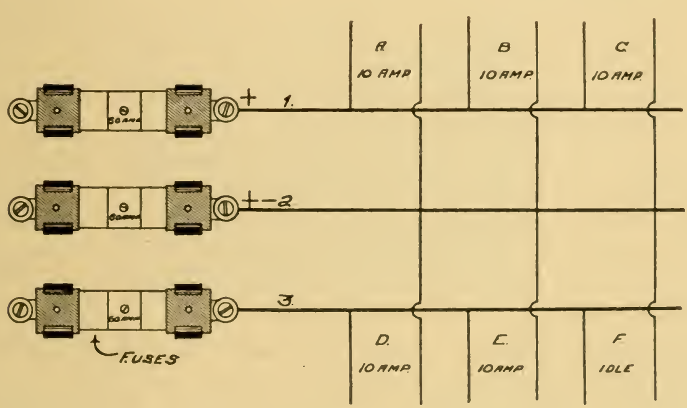


FIGURE 18

benefit by the greater power consumption. Here instead of using wattage equal to the amperage multiplied by the voltage of the neutral and one outside wire, the voltage of the two outside wires (twice that of the neutral and either outside wire) must be reduced to arc voltage. This indicates much waste power.

Assuming a 3-wire supply to be 110-220, and that 70 amperes are used at the arc, the total wattage consumed by connecting to outside wire *and* the neutral would be represented by 110 × 70 = 7,700 watts if current is taken through resistance. If we disregard the neutral and connect to the outside wires, then the wattage consumed would be 220 × 70 = 15,400 watts, or exactly twice as much as is required for the 110 volt connection.

(47) In Fig. 18 we have a diagrammatic representation of six house circuits fed by a 3-wire circuit, each wire of which is fused at 60 amperes. Circuit F is idle. Circuits A, B and C are each using 10 amperes, or a total of 30 amperes. Circuits D and E use a total of 20 amperes. Can we connect a projection arc circuit, the arc using 25 amperes, to circuit F? The offhand answer is: "No, the circuits are already using 50 amperes. A 25 ampere addition would overload the fuses." This is an error for the circuits are not using 50 amperes, but 30, ten of which are handled individually by the generator attached between the upper wire and the neutral.

Circuits AB and DE will burn in series, so that instead of 40 amperes at 110 volts, the lamps or motors on A, B and DE will work in series on 220 volts, and only a total of 20 amperes will flow.

Circuit C will use 10 amperes at 110 volts as long as circuit F is idle. This will have the effect of causing the upper wire to carry 30 amperes, the lower 20 and the neutral 10. Thus the upper fuse will be loaded at 30 amperes, the neutral at 10 and the lower at 20. The system, therefore, is unbalanced by 10 amperes. The generator attached to the true positive and neutral has 10 amperes more load than the other.

If we now connect a 25-ampere load (the projector arc, for example) to circuit F, the condition of overload is reversed, and the generator attached to the lower two wires will be carrying 15 amperes more than the other. The upper fuse now carries 30, the center 15 and the lower 45 amperes. Therefore it is evident that instead of being overloaded, none of the fuses would be working to capacity.

Measuring Unbalance

(48) You may always ascertain exactly how much

any 3-wire circuit is unbalanced by connecting an ammeter to each side successively, or by connecting it to the neutral wire between the first piece of current-consuming apparatus and the switchboard.

3-Wire System Wire Sizes

(49) To calculate wire sizes suitable for 3-wire systems, proceed as for ordinary 2-wire circuits, giving consideration only to the true negative and true positive—the outside wires. Having determined the necessary size for the outside wires, install a neutral of the same diameter.

Switches

(50) In Fig. 19 we see, at the top, what is known as a single-pole, single-throw knife-switch. It is a single-throw for the reason that it can make but one

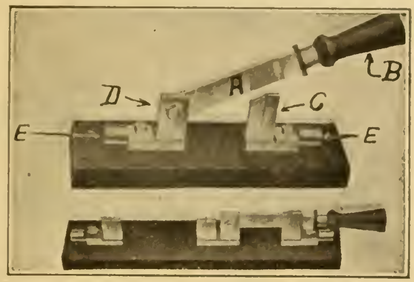


Figure 19

contact, namely with the copper spring clip, C. At the other end the "knife" or "blade" is permanently attached to clip D. The circuit wires are attached to lugs EE. The base upon which the parts are mounted is made of insulating material. When knife A is pulled out of clip C, the line is broken and all current flow is stopped. SPST is the recognized abbreviation of this type of switch.

(51) Immediately beneath this we see a single-pole, double throw SPDT switch. It is exactly like the one above except that at the left is a second copper spring clip with which the switch blade can make contact. This type

of switch may be used to connect a power using device quickly to either of two power sources. The power using device is connected with the center lug and the two power sources respectively to the two end clips. The action is obvious.

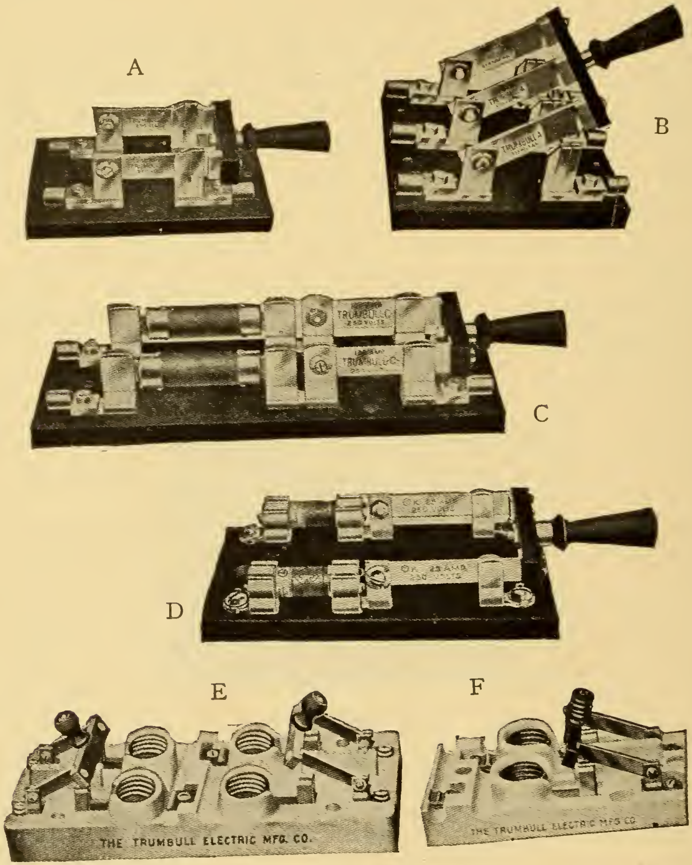


FIGURE 20.

(52) Such switches, either single or double throw, may be had with one, two, three or four poles—that is, knives or blades—and contacts. Several types of single throw switches are shown in Fig. 20 in which A is a single-throw double pole SPDT, B a single-throw triple pole SPTP switch and C and D are STDP switches with cartridge fuses attached. C has the knife and D

ferrule contact fuses. EF are types of porcelain base DPST knife switches used in theatres for various purposes.

How To Install Switches

(53) In a projection room switches must be located to allow for quick and easy manipulation.

(54) The tendency of knife switches such as are shown in Figures 19 and 20 to fall shut through the action of gravity must be avoided. The handle of double pole switches should swing sidewise. The handle of single throw switches should point upward.

(55) The knife blade switches should be examined at least once each week if used often. (56) Contact D, Fig. 19, should be snug to insure good electrical contact and to hold the blade in any position. Contact C should always be in good condition. Often the clip is split in its center, as is shown in C. Make certain that both portions of such clips make good contact with the blade. Keep insulation base clean to prevent current leakage. All portions of the switch should be snug and tight at all times including the cross bar and handle.

Enclosed Switches

(57) An enclosed switch has an individual protective covering, usually of sheet metal. The cover protects the switch from contact with various objects which might cause a short circuit or injury to the switch parts and also protects the user.

(58) Connections of enclosed switches should be arranged so that the blade will be electrically dead when the switch is open. (59) It is a rule that should be observed with all knife switches.

The following is taken verbatim from the National Electrical Code:

"Single-throw knife switches shall be so placed that gravity will not tend to close them. Double-throw knife switches may be mounted so that the throw will be either vertical or horizontal as preferred, but if the throw be vertical a locking device shall be provided, so constructed as to insure the blades remaining in the open position when so set.

"When practicable, exposed knife switches shall be so wired that blades will be dead when the switch is open."

Switch Location

The location of switches deserves careful attention. (60) First of all, under no circumstances should the emergency light switches be located on the main switch board. In case of fire an excited employee might pull this switch and plunge the entire theatre in darkness. (61) It is best to place emergency light switches in a locked box in the manager's office or in the box office where no one can get at them except the ticket seller and manager. The key to the box should be left attached to the box door. In the projection room local conditions will of course govern the location of the switches, but convenient accessibility should be the governing factor.

Careful About S. P. Switches

(62) Before installing a single pole switch be sure its use is not prohibited by Underwriters' or local regulations.

DPST switches ordinarily are used to control all incandescent, motor and projection circuits, except those on which DPDT or TPDT switches are required. TPDT switches are used for all 3-wire circuits. Generally the type of switch called for depends upon (a) the work it will have to do and (b) restrictions imposed by Underwriters' rules.

Switch Markings

(63) The National Electric Code requires that switches have certain dimensions, according to the voltage of the circuit they are connected to and the amperage they must carry. Both the voltage and amperage capacity must be stamped upon some part of every switch. Reject any switch not so marked.

A switch may be used for a circuit of any voltage less than it is marked for, or for any amperage less than its rating. (64) No switch may be used for a higher voltage or amperage than it is marked for. 250-volt switches are used in theatres almost universally. There is no switch made that is marked for 110 volts, the requirements for 110 and 220 volts being identical.

Metal Cabinets

(65) Unless switch cabinets are built into the projection room walls (as they should be) all circuit

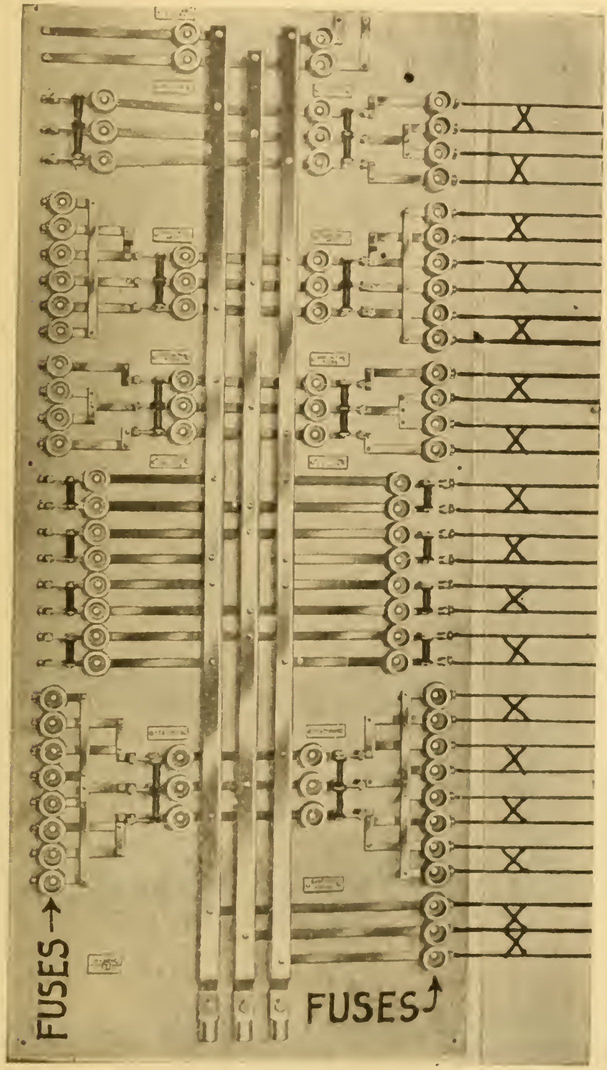


Figure 21

switches and fuses should be enclosed in a metal cabinet supplied with a self-closing door.

Switchboards

Large switchboards may appear to be complicated but are really quite simple. Study a large board and you

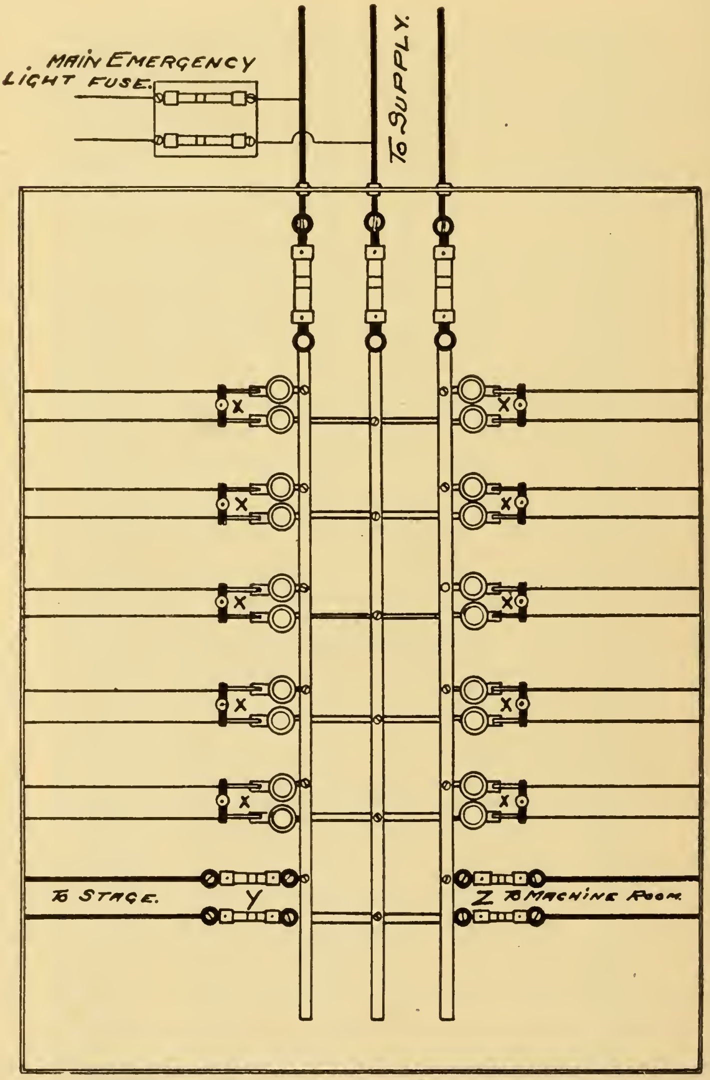


Figure 22

will be able to trace its connections with ease.

Fig. 21 shows a large board fed by a 3-wire circuit.

(66) In the three central flat copper bars called bus bars are (67) screw heads indicating electrical connection between the bus bars. At the bottom we see three of these screw heads, denoting that the three lugs leading to circuit wires are connected to the main bars. These lugs connect to a 3-wire circuit. Above this the lower bar connects to the left main bus bar, the next to neutral and the next to the right bar. On either side the sub-bars feed four 2-wire circuits. Fig. 22 is a diagrammatic view of a board fed by a three-wire circuit.

FUSES

Before entering into a discussion of fuses we will quote again from the National Electrical Code:

LINK FUSES

Link fuses shall not be installed except by permission of the authority enforcing this code. When used in capacities from 601 to 1500 amperes they shall be of dimensions and other characteristics specified in paragraphs a to d inclusive of Section 802 of the 1930 edition of this code.

ENCLOSED FUSES

Enclosed fuses shall be classified to correspond with the several classes of standard cutout bases and shall be so designed that it will be impossible to put any fuse of a given class into a cutout base which is designed for a current of voltage lower than that of the class to which the fuse belongs.

Each fuse shall be marked with its amperage capacity. On ferrule contact fuses this marking shall be on the tubes or ferrules and on knife-blade fuses, on the tubes or caps. In addition to the above marking each cartridge fuse shall be provided with a paper label, red for 600-volt fuses, navy blue for 250-volt fuses of 15 amperes or less capacity, and green for 250-volt fuses of over 15 amperes capacity. Such labels for cartridge fuses shall bear the following: the name or trademark of the manufacturer and the voltage for which the fuse is designed.

Plug fuses of 15 amperes capacity or less shall be distinguished from those of larger capacity as follows: by an hexagonal opening in the cap through which the mica or similar window shows, or by some other prominent hexagonal feature such as the form of the top or cap itself, or an hexagonal recess or projection in the top or cap.

The styles of enclosed plug and cartridge fuse terminals shall be as follows:

Not over 250 volts.

0- 30	Amps.	A. Cartridge fuse (ferrule contact). B. Approved plugs or cartridge fuses in approved casings, for use with screw-shell plug cutout bases.
31- 60	"	Cartridge fuse (ferrule contact).
61-100	"	Cartridge fuse (knife-blade contact).
101-200	"	
201-400	"	
401-600	"	

Not over 600 volts.

0- 30 Amps.	Cartridge fuse (ferrule contact).
31- 60 "	Cartridge fuse (ferrule contact).
61-100 "	Cartridge fuse (knife-blade contact).
101-200 "	Cartridge fuse (knife-blade contact).
201-400 "	Cartridge fuse (knife-blade contact).
401-600 "	Cartridge fuse (knife-blade contact).

(68) An electric conductor of given diameter and composition, of commercial copper, for example, will carry a fixed number of amperes only without overload. (69) But it is always possible that something such as a ground, "short" or rise in voltage will cause an abnormal current to flow and overload a circuit, setting up a bad and dangerous condition.

TABLE NO. 5

Form 1. CARTRIDGE FUSE—FERRULE CONTACT

Voltage	Rated Capacity. Amperes.		A Length Over Terminals. Inches.	B Distance between Contact Clips. Inches.	C Width of Contact Clips. Inches.
Not over 250	0-30 31-60	Form 1	2 3	1 1¾	½ ⅝
	61-100 101-200 201-400 401-600	Form 2	5⅞ 7⅛ 8⅝ 10⅜	4 4½ 5 6	⅞ 1¼ 1¾ 2⅛
Not over 600	0-30 31-60	Form 1	5 5½	4 4¼	½ ⅝
	61-100 101-200 201-400	Form 2	7⅞ 9⅝ 11⅝	6 7 8	⅞ 1¼ 1¾

(70) To guard against this we have the "fuse," which is a short piece of conductor made from an alloy that will melt at far lower temperature than copper. (71) The fuse is usually connected to both wires of a circuit, as shown in Fig. 22A, though in actual practice raw wire is seldom used. (72) Fuses will melt quickly at low temperature, when wires become overloaded and their

temperature rises. They present a definite and reliable element of safety. When fuses melt all current flow is stopped until a new fuse has been installed.

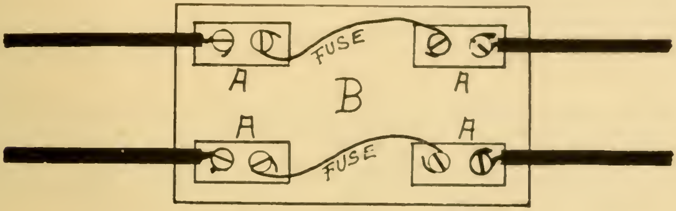


FIGURE 22A

(73) But before a new fuse is installed the current should be, of course, reduced to normal, by repairing whatever has caused the overload.

TABLE NO. 6

Form 2. CARTRIDGE FUSE—KNIFE BLADE CONTACT

D	E	F	G		
Diameter of Ferrules or Thickness of Terminal Blades. Inches.	Min. Length of Ferrules or of Terminal Blades outside of Tube. Inches.	Dia. of Tube. Inches.	Width of Terminal Blades. Inches.		Rated Capacity. Amperes.
9/16 13/16	½ ⅝	½ ¾		Form 1	0-30 31-60
⅛ 3/16 ¼ ¼	1 1⅜ 1⅞ 2¼	1 1½ 2 2½	¾ 1⅛ 1⅝ 2	Form 2	61-100 101-200 201-400 401-600
13/16 1-1/16	½ ⅝	¾ 1		Form 1	0-30 31-60
⅛ 3/16 ¼	1 1⅜ 1⅞	1¼ 1¾ 2½	¾ 1⅛ 1⅝	Form 2	61-100 101-200 201-400

(74) It is interesting to note that with increasing temperature the temperature co-efficient of fuse wire rises much more rapidly than that of copper.

(75) Fuses are available for theatre work in three

forms: link, cartridge and plug. (76) The link fuse is used in metal cabinets wherever local regulations require them for projection circuits because it is difficult to "boost" them without the trick being immediately evident upon inspection.

Cartridge Fuses

(77) A cartridge fuse consists of two brass or copper terminals joined by fuse wire inclosed in a paper barrel filled with a powdered non-inflammable insulating material. Inside this barrel, embedded in the

Figure 23

powder, is a pilot wire which is much smaller than the main fuse wire. It always passes immediately under a paper label pasted on the surface of the fuse barrel. The object of this is that when the main fuse wire melts the pilot will also melt, and in the process will scorch the paper label so that the melted fuse may be identified at once. This usually works out all right, but not always. An unburned label is not positive proof that a fuse is not blown.

In Fig. 23 we see two forms of cartridge fuse contact, namely the ferrule A and the knife blade B, together with their receptacles.

In Fig. 24 we have a view of the construction details of a cartridge fuse of ferrule contact type. The knife blade fuse is exactly the same, except for its contacts. The drawing is self explanatory.

Plug Fuses

(78) Plug fuses such as are shown in Fig. 25 consist of a porcelain base having a brass collar on which is a thread that will fit into any standard plug fuse socket. The brass thread of B, Fig. 25, is attached to one binding post and the contact at center of bottom of B to the other.

If one wire of a circuit is cut and the ends attached to the binding posts of the socket shown at B, Fig. 25, and the brass thread and center contacts of the plug is

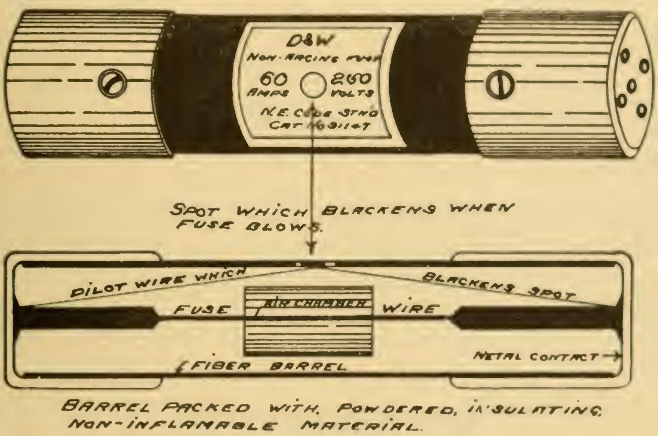


Figure 24

joined with a fuse wire and the plug screwed into the socket, the circuit wire will thus be made complete again.

In practice the fuse wire of a plug fuse is attached between the center contact and the thread. The plug is then covered with a protective cap in which is a mica "window" through which the fuse wire may be examined. In Fig. 25, at A we have two views of a plug fuse. C is the plug with brass-mica cap removed. D is a special form of plug fuse to be used on amperages up to 60, the regular plug fuse having a maximum capacity of 35 amperes. Plug fuses may be used for any sort of work up to the limit of their capacity.

Link Fuses

(79) A link fuse is nothing more than a fuse wire at each end of which is attached a copper clip, as shown in Fig. 26. They must not be used except by order or consent of the authorities, and then only in metal or other approved cabinet provided with a self-closing

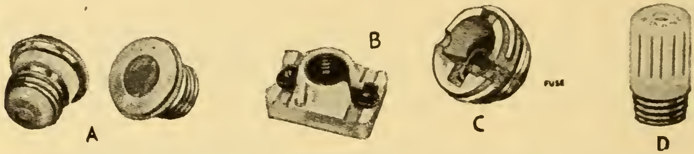


Figure 25

door. Their use in theatres is not permissible anywhere except inside the projection room.

Boosting Fuses

(80) "Boosting" a fuse consists in increasing its capacity by creating a metallic by-pass, consisting usually of a small copper wire, or in the case of plug fuses, a copper coin so arranged that when the fuse is in place the coin forms contact with the two fuse terminals.

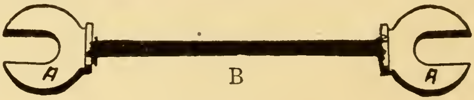


Figure 26.

(81) A "boosted" fuse no longer serves its purpose of protecting the circuit wires and apparatus attached thereto. If the "boost" be sufficiently heavy, as is usually the case where such practice is resorted to, both wires and apparatus are left without any real protection. Under this condition not only are wires and apparatus in grave danger of injury but the circuit wires may be heated to such high temperature as to cause fire.

Never fuse a lighting circuit above the normal rated capacity of its wires or above the combined capacity of the lamps taking current from it, though in the latter case a margin of ten percent is allowable.

Never fuse a motor circuit above the rated capacity of its circuit wires. The Board of Underwriters permit the motor or motors to be fused at 25 per cent above capacity but this requires that the motor circuit wires have a capacity of at least 25 per cent above the equipment they serve.

Fusing Projector Circuits

(82) Projector circuit wires and switches should always be of sufficient capacity to carry current considerably in excess of the maximum requirement for normal work. When that is the case it is permissible to fuse circuits 25 percent above the normal current demand. Thus, if the normal current demand is 100 amperes, fuse to 125 amperes, and fuse other normal current flows in the same proportion as closely as stock fuse capacities will permit.

When a projector light source circuit fuse blows, a switch, as shown in Fig. 27, may be thrown over, cutting a new set of fuses into operation. This switch should be installed as a precautionary measure for each projection circuit.

Fusing Motor Generators

(83) While it is not required, it is good procedure to install fuses on both primary and secondary sides of motor generator sets. A good, safe rule is to fuse 20 per cent in excess of the maximum current requirements on both primary and secondary sides.

Extra Fuses

(84) All projection rooms should have a plentiful supply of fuses of all types and capacities. When the proper fuse is not immediately available it is possible to temporarily protect a circuit with one fuse, bridging the other contacts with copper.

(85) Wire fuses are always unreliable but copper is regarded best in an emergency. Table 7 shows the fusing point of small copper wires.

Asbestos covered wire strands usually are No. 30 or 31. By combining these strands a temporary fuse of almost any desired capacity can be made. Five strands would be approximately right to carry 40 amperes. A temporary fuse made thus would be more reliable, we believe, than would a single larger wire.

TABLE NO. 7
APPROXIMATE FUSING POINT OF SMALL COPPER WIRES

No.	Amperes	No.	Amperes	No.	Amperes
30 ...... @	 10	25 ...... @	 25	21 ...... @	 50
28 ...... @	 15	24 ...... @	 30	20 ...... @	 60
26 ...... @	 20	23 ...... @	 40	18 ...... @	 70

When Fuses Blow

(86) If a fuse lets go and the new one blows immediately after it is installed this is positive proof that something is wrong. It is probably a "short" or heavy ground. Leave the circuit dead until the trouble has been located and repaired. (87) Should the new fuse blow only after a lapse of time it is possible that the trouble is due to poor contact. (88) This points to the necessity for examining fuses at intervals because they readily generate heat when loose or dirty. (89) Fuses used on a 110 volt current must be inspected regularly.

Often a rise in voltage will force enough additional current through to blow a fuse. The danger is instantly obvious because all incandescent lamps will burn above normal brilliancy.

Where Fuses Are Installed

(90) In general, fuses should be installed as follows: (a) Main service fuses, located on the street side of the main house switch. These fuses carry all current used in the theatre except exit and other lights ordinarily kept burning while the performance is in progress, and the stage lights where the stage is served by a separate service circuit. (b) All circuits supplying emergency lights including exit lights and those lights kept burning

while the performance is in progress should have separate fuses, located, preferably, in the box office. The circuit they protect should join the main service circuit on the street side of the main switch and fuses. (c) Every separate circuit in the theatre must have its own fuses. (d) Fuses should be installed wherever a change in wire size occurs. (e) Main fuses in projection room carrying all current used therein, also fuses for each circuit in the projection room. (f) Fuses for each individual emergency light circuit, particularly as applied to exit lights.

Fuse Markings

(91) Cartridge and plug fuses are marked with both their voltage and amperage capacity. Markings are usually on the paper barrel of the cartridge fuses and stamped into some metallic part of plug fuses. Markings of link fuses should be on one of the copper contacts. Reject all unmarked fuses.

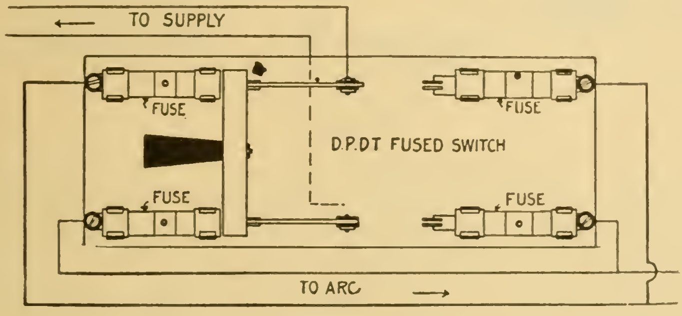


Figure 27

Testing Fuses

(92) Fuses may be tested by a simple device like that illustrated in Fig. 28, in which D is a block to hold a single ferrule fuse, C a lamp receptacle and an ordinary incandescent lamp of proper voltage and convenient candle power. E is a plug fuse receptacle. A and B are any two nearby live circuit wires. If either a good cartridge or good plug fuse is inserted, the lamp will light up.

Making Wire Splices

Every wire that does not lead directly to a high temperature terminal such as a rheostat or projection lamp should terminate in a soldered lug.

(93) To attach a lug, first remove the insulation from the wire end for a distance equal to the depth of the lug hole. (94) To do this, run your knife around the insulation cutting straight in, but not far enough to

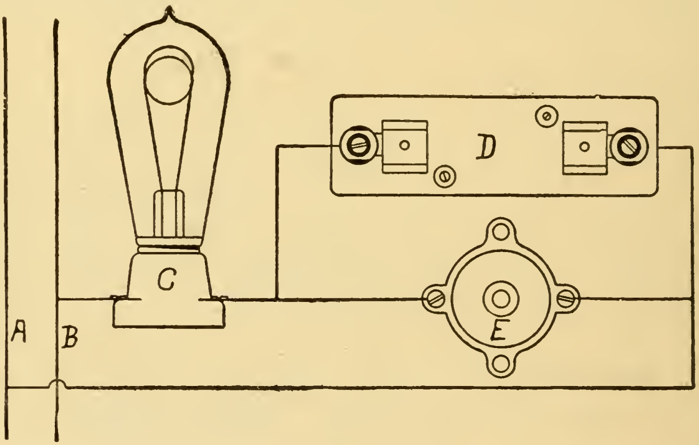


Figure 28

touch the wire itself. If the blade edge touches the wire it will probably cut a shallow ring around it and the wire may later break easily at this point.

Having removed the insulation, scrape the surface of the copper clean and apply good soldering acid or compound sparingly to both wire and lug. Next, using any convenient instrument, usually a blow torch, fill the lug hole with melted solder, having first cleaned the wire end and heated both the lug and wire end slightly. Then, holding the lug with a plyer, carefully insert the wire end into the solder and shove it down to the bottom of the hole.

To make a wire splice proceed as follows: Remove the insulation from both wire ends. (95) Whittle the insulation away as you would whittle a lead pencil so that you will not cut into the wire. (96) Scrape the wire ends perfectly clean and twist them together tightly as shown in the last illustration of Fig. 29. (97) Then, being careful not to heat them too hot during the process (which tends to raise its resistance) and using an approved solder flux, solder them tightly together and (98) wrap the completed splice first with rubber and then with insulating tape to the thickness of the original insulation.

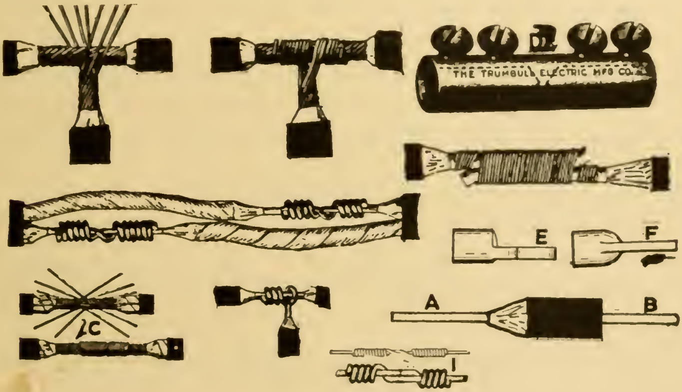


FIGURE 29

In Fig. 29 we see various methods of making splices. One is called the Western Union Joint. A shows the proper way to remove the insulation for splicing. B is the way to do it when installing a lug. Whatever method you use in binding the wires together, (99) it must be mechanically perfect before filling with solder. (100) The following solder flux compounded cheaply by any druggist works well on either copper or tin.

Saturated solution of zinc chloride....	5 parts
Alcohol.	4 parts
Glycerine	1 part

Paste solder flux may be purchased, ready to use. For hot joints where solder would melt, special non-solder clamp lugs of various sorts are obtainable from any supply dealer.

LENSES

1. Why must the projectionists understand certain laws relating to light action?
2. Recite the law dealing with light from open sources.
3. Examining Fig. 30, what effect would you say has distance from an open light source upon a surface to be covered by the light?
4. Does light travel in straight lines?
5. Under what circumstance does a light ray change its course?
6. What effect has distance from an open light source upon brilliancy of illumination?
7. What optical train is particularly difficult?
8. What does the first optical system of a motion picture projector do?
9. What is the second optical system of a projector and what does it do?

DEFINITIONS, PAGE 104

10. What is the Angle of Incidence?
11. What is meant by Angle of Refraction?
12. What is meant by Barrel Distortion?
13. What is a plano-convex and a bi-convex lens?
14. What is meant by Brilliancy?
15. What is meant by Collector Lens?
16. Describe a compound lens.
17. What does the term Conjugate Foci mean?
18. What is meant by Converging Lens?
19. In projection optics what is meant by a Condenser?
20. What is Chromatic Aberration?
21. What is meant by Equivalent Focus?
22. Do the faults in a simple lens alter its focal length?
23. What is meant by Critical Angle?
24. What does the term Focal Length mean?
25. What is meant by Free Diameter with reference to lenses?
26. What is Incidence?

27. By what means are lenses corrected?
28. What is a light ray, or a ray of light?
29. What is a Meniscus Lens?
30. Optically, what does the term Perpendicular mean?
31. What is meant by the Plane of a lens?
32. Describe a plano convex lens.
33. What is the Principal Axis of a lens?
34. What is the Projection Angle?
35. What is Refraction and what causes it?
36. What is meant by a Simple Lens?
37. What is Spherical Aberration?
38. What is meant by Working Distance of a projection lens?
39. What difference is there between Working Distance and Back Focus?

LENS ACTION, PAGE 108

40. Upon what is lens action wholly based?
41. Does each pin-point of the surface of a lens refract light differently?
42. Does a light ray change its course while passing through the body of a lens?
43. Upon what three things is lens action upon light dependent?
44. If a ray of light meets both surfaces of a lens exactly at right angles what will happen?
45. If a light ray meets a lens surface at an angle what happens?
46. Explain the various points in connection with Fig. 33.

IMAGE FORMATION, PAGE 111

47. Examining Fig. 34, explain how the image of object X is formed.
48. Are uncorrected lenses faulty and how may they be corrected?

FOCAL LENGTH, PAGE 112

49. What is meant by the focal length of a simple lens?.
50. By what elements of a lens is focal length chiefly affected?

Lens Curvature, page 113

51. Of what surface are the surfaces of lenses (except parabolic) used in projection duplicates?
52. What would be the optical result of placing two plano-convex lenses with their flat surfaces in contact?
53. What is the effect of spherical aberration?
54. In what way may spherical aberration have considerable value?

Lenses Cannot Focus Objects to a Point, page 114

55. Explain why it is impossible for any lens to focus any object to a point.
56. In just what manner is an image formed by a lens?

The Projection Lens, page 114

57. What kind or variety of lens is the projection lens?
58. Does balsam sometimes deteriorate or "melt"? What must be done if it does?
59. What is the advantage and disadvantage of cementing the rear lenses?
60. If one element of a compound lens is injured or broken, must the whole lens be sent to the manufacturer for repair?
61. Why must the broken part of a lens be included in the shipment?
62. Have odd lenses or parts of compound lenses any value?

Ordering Lenses, page 115

63. When ordering lenses, what data must be supplied to insure proper selection?

Range of Projection Lens Focal Lengths, page 116

64. What focal length projection lenses are carried regularly in stock by manufacturers and some dealers?

65. What is the safest method of matching a lens?
66. What information should be transmitted to the manufacturer in ordering a lens to match another?
67. Describe the marking used by one lens manufacturer.
68. How are matched lenses marked?

Light Loss Through Reflection, page 117

69. What, according to optical engineers, is the reflection light loss per surface?
70. To what else is light loss due?
71. Is light loss the only evil effect of dirty lenses?

Cleaning Lenses, page 118

72. Does a very small amount of oil injure results?
73. Do even the faintest finger marks do harm?
74. How may faint finger marks be made visible?
75. What is best for cleaning lenses?
76. How often should lenses be examined?
77. When should mirrors be cleaned?
78. Should projection lenses be disassembled occasionally, the interior surfaces of the lens elements cleaned and the lens coating examined?
79. Why is the projection lens barrel painted black inside?
80. What should be done if the black interior coating wears off?
81. What should all projector lenses makers do?
82. What marks should be affixed to projection lens elements by projectionists?
83. What should projectionists be very cautious about in disassembling and reassembling projection lenses?
84. Just how tightly should the mount be screwed up when assembling lenses?

Loss Through Absorption, page 119

85. How much light is absorbed in passing through crown or flint glass?
86. What is the loss in poorer grades of glass?

Testing for Barrel or Pin-Cushion Distortion, page 120

87. What is the effect of barrel distortion; of pin-cushion distortion?
88. Should projectionists test their lenses for barrel and pin-cushion distortion?
89. How test for barrel or pin-cushion distortion?

Testing for Flatness of Field, page 120

90. Describe a simple process of testing a projection lens for flatness of field.

The Why and Wherefore of Focusing, page 121

91. Does a cone of light go forward from every pin-point of the film photograph?
92. What is the function of the projection lens with relation to the cones of light from each pin-point of the film photograph?
93. If distance from the film photograph to the projection lens is altered in the least degree, what happens?
94. Examine Fig. 38 and explain the action it illustrates.

Depth of Focus, page 121

95. Is depth of focus definitely a physical condition?
96. To what is depth of focus proportional?
97. Do all lenses of equal diameter, equal correction and equal focus have also equal depth of focus?

Altering Focal Length, page 122

98. Is it possible to alter the E.F. of a projection lens by lengthening or shortening the distance between front and back factors without injury to the lens?

Picture Dimensions and E. F. of Projection Lens, page 122

99. Can any projection lens be made to project a picture at any distance?

100. Will any projection lens project the same size screen image at different distances?
101. What effect has longer or shorter E.F. upon working distance?

Measuring Focal Length of Simple Lenses, page 122

102. Is it possible for projectionists to measure the focal length of simple lenses—a plano-convex lens for example—accurately?
103. Is it possible to measure simple lenses with sufficient accuracy to serve all practical purposes for projection work?
104. Describe the process of measuring the focal length of a simple lens.
105. How may the focal length of bi-convex lenses be measured?
106. What rules govern the measuring of the focal length of simple lenses?
107. How would you measure the working distance of a projection lens?

Measuring Equivalent Focus, page 123

108. Describe the process of measuring the equivalent focus of a projection or other compound lens.

Working Distance and Lens Diameter, page 124

109. Is the working distance and the lens diameter often of great importance?
110. How may the projectionist ascertain whether or not the beam all enters the projection lens?
111. If a plano-convex condenser is used will the beam enter the lens in its entirety?
112. How may the divergence of a beam be reduced and what is the objection to doing it?
113. How may projectionists discover that unevenness of screen illumination is inevitable if the light does not all enter the lens?

Projector Optical Train, page 128

114. Of what does the projector optical train consist?
115. Describe the function of the first element of projector optical train.

116. What is the function of the second element of the projector optical train?
117. What is the first point of efficiency to be considered?
118. What is the effect of increased distance of the light source to the collector?
119. What limitations govern the distance of the light source to the collector?
120. What difficulty does the thin-edge, thick-center collector lens set up when working with a high-power electric arc?
121. What is one effect of a heavy arc tail-flame?
122. How may the collector be guarded from some portion of the tail flame heat?
123. What should the focal length of a plano-convex condenser collector lens always be?

Lense Pitting, page 130

124. How are collector lens pitted and is there any practical way of preventing it?

The Collector, page 131

125. What should be the focal length of the collector of a plano-convex condenser?
126. What should be the focal length of a converger?
127. Why should convex surfaces be placed next to each other in plano-convex condensers?

Spacing Condenser Lenses, page 131

128. Why should condenser lenses be as close together as possible without actual contact?
129. Does the collector of a plano-convex condenser send forward a parallel beam of light?

The Converging Lens, page 131

130. Upon what is the spot diameter dependent?
131. How should the projectionist select his condenser?

MIRROR COLLECTOR CONVERGER, PAGE 132

132. What office does the mirror collector serve?
133. Describe the effect of spherical aberration in such mirrors.
134. Do all such mirrors have this fault?
135. May spherical aberration in such mirrors be corrected?
136. What constitutes the parabolic or the eliptical mirror?
137. What is the practical effect of spherical aberration?
138. Is spherical aberration detrimental to good projection?
139. Will a properly installed mirror converger collect more light than the 4½ inch diameter plano-convex condenser?
140. Examine Figs. 45 and 46 and explain the points raised in the text covering them.
141. Is the mirror a more efficient collector of light than the plano-convex condenser?
142. Name one reason why the reflector type arc produces a hotter spot than an arc with which a plano-convex condenser is used.
143. Name one advanatge of locating the rotating shutter between the light source and the aperture source.
144. Is the mirror an efficient light collector as compared with the glass condenser?
145. Explain the real cause of spherical aberration in a spherical mirror working with a projector light source.
146. How may spherical aberration be corrected?
147. Explain the reduction or enlargement of the spot diameter caused by advancing or retarding the light source from the mirror.
148. What two surfaces present the highest possible accuracy and efficiency in light reflection?
149. What is placed on the back of the mirror?
150. What backing is applied on top of the silver?
151. Is it essential to locate the light source at a certain fixed distance in the mirror surface, and the mirror a fixed distance from the aperture?
152. What is the distance from the light source to the mirror vertex called?
153. What term is applied to the distance from the mirror vertex to the aperture?
154. Must mirror focus and mirror working distances be maintained exactly?
155. Are these distances different for mirrors of different focal lengths?

156. How closely must these distances be maintained?
157. What types of glass are best for mirrors?
158. Name two points essential to efficient operation of mirrors.
159. How often should mirrors be wiped off?
160. What cleaning fluid is best for mirrors?
161. How should mirrors be cleaned when a flaming high intensity arc is used?
162. How often should the mirrors be removed for washing and how should they be washed?
163. What should be done when the silver tarnishes?
164. What should be done if the mirror is pitted or scratched?
165. Is it profitable to continue to use a scratched or pitted mirror?

CHAPTER V.

LENSES AND MIRRORS

(1) Before the projectionist can hope to deal intelligently with lenses and their action upon light, he must understand certain basic laws, one of which has to do with light intensity at varying distances from an open light source. It reads:

(2) "Light intensity decreases inversely as the square of the distance from its source."

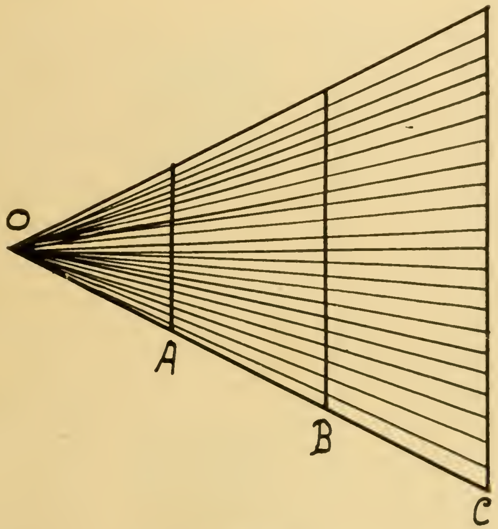


FIGURE 30

(3) In Fig. 30 we see an open light source with three screens, A, B and C, located one foot, two feet and three feet respectively from the light. Screen A, we will assume, is exactly one foot high and one foot wide. It therefore represents one square foot of area. Screen B located two feet from the light, has twice the dimensions of screen A and is 4 feet square. Screen C is 3 feet

from the light source and is 3 feet wide by 3 feet high and is therefore 9 square feet in area. A fourth screen located 4 feet from the light source reaching to the same boundary lines would be 4 feet high, and if it were also 4 feet wide would have 16 square feet of area.

(4) Light travels in perfectly straight lines through any transparent medium that is of even density throughout.

(5) It changes its direction only upon encountering a medium of different density at an angle.

Barring a change of direction the rays will travel as indicated by the black lines within the space bounded by the outer lines so that if screen A is removed the rays will cover screen B exactly and if both screens A and B are removed, they will cover screen C, and so on indefinitely.

(6) Considering these facts we discover that, since screen B has four times the area of screen A, doubling the distance quadruples space the rays will cover. The illumination of screen B will be only one-fourth as brilliant as screen A, assuming that both screens have equal powers of reflection. Stated differently, the surface of screen B is four times as great as that of screen A. The light has equal power of illumination at both screens but at screen B it is spread over four times as much surface. Hence the illuminating power per unit area is decreased in the ratio of four to one. If another screen square in shape and reaching to the same diverging boundary lines were located four feet from the light source, it would be 16 square feet in area. The ratio of decrease in illumination would then be 16 to 1. An understanding of this law is especially important in connection with the distance of the light source from the collector lens or mirror.

(7) Projectionists are called upon to handle very difficult optical systems. This is particularly true of the motion picture projector, in which two separate optical systems are combined, one of them highly corrected and one either not corrected at all or only partially so. (8) These systems are so joined that the first picks up

diverging light rays from the light source, converges them upon the projector aperture near which it forms a more or less out of focus image of the light source. This

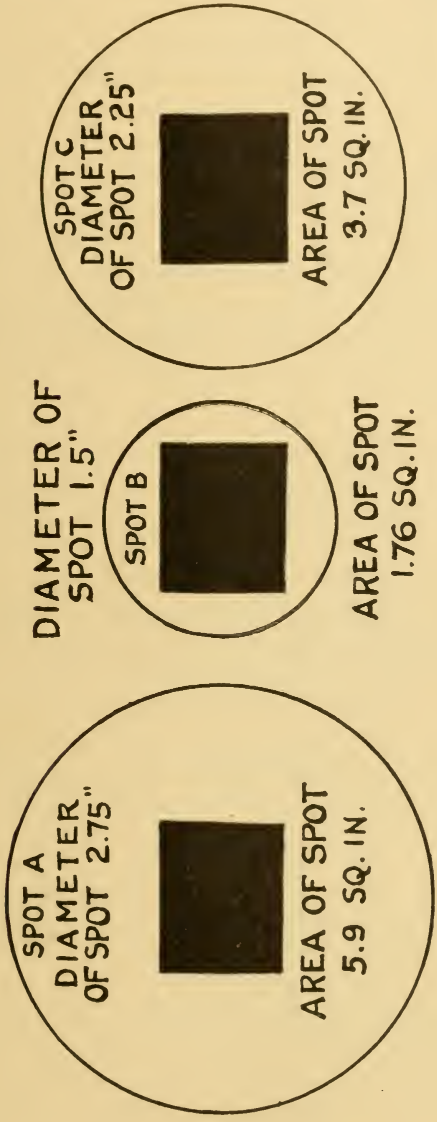


Fig. 31.—Illustrating the possibility of loss of light at a given point. Total light passing through apertures Spot A, 13%; loss of light at Spot A, 87%. Total light passing through apertures Spot B, 43%; loss of light at Spot B, 57%. Total light passing through apertures Spot C, 19%; loss of light at Spot C, 81%.

system may be either a single lens glass condenser, a 2-lens glass condenser or it may be a spherical, an elliptical or a parabolic mirror, working either with or without a converging lens of glass.

(9) The second system consists of a projection lens (a compound lens, usually made up of two elements separated slightly by a metal spacing ring and two other elements cemented together with Canadian balsam, the whole contained in a brass barrel) which picks up a bundle of light rays emanating from every one of the tens of thousands of pin points in the film photograph posed over the projector aperture. This lens receives and so refracts the rays that each reaches exactly its appointed place in the screen image they combine to form. Thus the enormously magnified image is sharp and clear when viewed from a reasonable distance.

Definitions

Although this volume contains an extensive glossary of terms, some definitions are given below that are important to an understanding of the optics of projection.

Angle of Incidence

(10) Angle a light ray forms with a line at right angles to any surface at the point of contact.

Angle of Refraction

(11) Angle a light ray forms with a line at right angles to the surface of lens at the point of entering or leaving it.

Barrel Distortion

(12) Uncorrected lenses so distort straight lines in the screen image that they are more or less curved.

Bi-Convex Lens

(13) A lens that is convex on both sides. See Figure 31 on page 103.

Brilliancy

(14) Intensity of illumination as measured in foot candles.

Collector Lens

(15) The lens of a 2-lens condenser that is next to the light source and therefore collects the light.

Compound Lens

(16) An assemblage of lenses mounted to form one lens.

Conjugate Foci

(17) A term having reference to two points, one of which is the light source or an object, the other the point at which the image of such light source or object is formed. It is the distance of the optical center of the lens from each of these points. If the distance to one of these points is altered, the other also is automatically altered. If one is moved nearer the lens the other will automatically be moved further away.

Converging Lens

(18) The lens of a 2-lens condenser that is located farthest away from the light source. The lens that converges the light upon the projector aperture and cooling plate. The prismatic condenser and the mirror, when used, act as both collector and converger, except where a mirror is used in conjunction with a lens, as is done in one equipment.

Condenser

(19) In projection optics, a lens or combination of lenses by means of which rays from the light source are collected and converged upon the projector aperture and cooling plate.

Chromatic Aberration

(20) An uncorrected lens, or an improperly corrected lens that tends to separate white light into its component elements or colors, focusing the colors at different distances from the optical center of the lens. This fault is corrected by combining lenses of crown and flint glass having convex and concave surfaces. In other words positive and negative lenses.

Equivalent Focus

(21) A term (commonly abbreviated as E. F.) used only with relation to lenses having two or more elements, of which the projection lens is an excellent example. In effect it means that the lens, viewed as a whole, has the same power of magnification or reduction as a simple lens having the same focal length as the E. F. of the compound lens.

(22) Although the simple, uncorrected lens possesses such faults as spherical and chromatic aberration and cannot project the same sharp image that a corrected compound lens does, these faults do not, in any degree, alter the focal length of the simple lens.

Critical Angle

(23) Light passing through a transparent medium of one density will, upon contacting a transparent medium of greater density enter it, but with a certain percentage of reflection loss. If, however, the angle of incidence is too great, the light will not leave the lighter medium and enter the heavier. Instead it will be reflected from the surface of the heavier medium in its entirety. The critical angle varies with different mediums. It is approximately 41° between air and polished glass.

Focal Length

(24) Distance between optical center of a lens and the object when its image is in sharpest focus.

Free Diameter

(25) The diameter of a lens that is free and open to the passage of light.

Incident

(26) Optically "incident" means contact. "Light is incident upon" means it is in contact with some surface.

Lens Correction

(27) The grinding of lens surfaces and the combining lenses of glass of different refractive indices so that

spherical aberration, chromatic aberration and other faults inherent in simple, single lenses are corrected.

Light Ray

(28) A thin line of light having no appreciable area of cross section.

Meniscus Lens

(29) A lens having one flat and one concave, or two concave surfaces. A lens that tends to diverge rays of light leaving it. See Fig. 31.

Perpendicular

(30) Optically, perpendicular means at right angles to.

Plane

(31) As applies to a lens, a line passing through its diameter exactly at right angles to its principal axis.

Plano Convex Lens

(32) A lens that is flat on one side and convex on the other. See Fig. 31.

Principal Axis

(33) An imaginary line passing through the exact center of a lens precisely perpendicular to its plane.

Projection Angle

(34) The angle between the axis of the projected light beam and a horizontal line.

Refraction

(35) The bending of light rays caused by leaving a transparent medium of one density and entering a transparent medium of different density. Refraction is based upon the following law: Light rays travel in perfectly straight lines through any transparent medium of uniform density. They are refracted (their course altered) in the act of leaving one medium and passing into another of different density, provided entry into the second medium is at an angle to its surface. There is no refraction if there is no angle of incidence.

Simple Lens

(36) A single, uncorrected lens.

Spherical Aberration

(37) That quality of an uncorrected lens that focuses light rays passing through its various zones (at different distances from its axis) at different distances from the optical center of the lens. The further from the axis a ray passes through, the closer to the lens it will be focused.

Working Distance

(38) As applies to a projecton lens, the distance from surface of photographic emulsion on film, when it is in position over the projector aperture, to rear or first surface of the lens.

(39) There is a difference between "working distance" and "back focus," with which it is often confused. "Back focus" is a technical term indicating the distance of film emulsion to first surface of the lens when light rays illuminating the aperture are parallel—a condition never found in projection. Back focus therefore is a term that cannot be used correctly in the lexicon of projection optics.

Lens Action

(40) The action of lenses upon light is based upon the principle that if a ray of light, on passing through a transparent medium of one density encounters the surface of another transparent medium of heavier or lighter density, at an angle, and enters it, the course of the ray will be altered. How much the ray will be "refracted" in passing at an angle into the medium of different density depends upon (a) the difference in density of the two mediums and (b) the angle at which the surface of the second medium is met.

(41) From the optical engineer's viewpoint each tiny pinpoint of a curved lens surface presents an entirely separate proposition from every other pinpoint of the lens surface, even though the two points join each other. Each point presents a different angle to light rays than

any other point, even though it is an adjoining one. Each point therefore refracts an incident light ray in a different direction than do all other points.

(42) In passing through the lens surface upon entering, the light ray receives its initial refraction. The amount of refraction depends upon the angle of incidence and the refractive index of the glass. If the glass

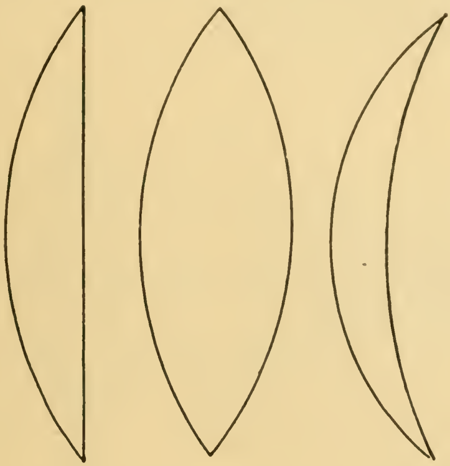


FIG. 32.—Left, plano-convex; center, bi-convex; right, meniscus lens.

is homogeneous (of even density throughout) the light will pass through it in perfectly straight lines until the opposite surface of the lens is reached. If the light reaches the second surface at an angle (as it must unless it was incident upon the first surface at the axis of the lens, and perpendicular to the surface at that point) the ray will again be refracted in passing from the lens.

(43) From this we perceive that if a lens is homogeneous its action upon light may be ascribed to the following elements: (a) the refractive index (density) of the glass; (b) the angle at which the lens surface is met at both of its surfaces; (c) the relative density of the medium through which the light passes before it reaches lens and (d) the lens itself.

(44) If a light ray meets a lens surface exactly at

right angles both upon entering and leaving, it will pass straight through without being refracted in any degree. There will be loss at both surfaces through reflection, that will vary widely with the perfection of polish and the cleanliness of the surfaces.

(45) Where the ray meets the lens surface at an angle there is not only refraction but also greater reflection, both refraction and reflection increasing as the angle of incidence increases.

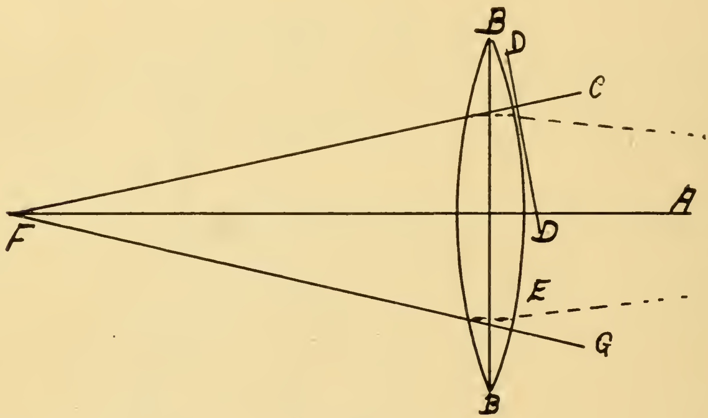


FIGURE 33

(46) Fig. 33 shows a bi-convex lens. FA represents the principal or optical axis, BB the plane of the lens and F is a point representing the center of a circle which the lens surface furthest away would form if the line representing its surface were continued; DD is a line representing the plane of the curved surface of the lens at the exact point ray FC enters; FC and FG are light rays.

Were FA a light ray, since it both enters and leaves the lens perpendicularly to both surfaces, it would not be refracted and would pass through straight as shown. Ray FC enters the lens at a considerable angle. The air and glass being of different density, the ray is refracted somewhat as shown by the dotted line; it passes straight through the body of the lens until it meets the second surface, also at an angle, whereupon it is again refracted, though less than at the first surface because the angle of incidence is less. There is a loss by reflection at both surfaces.

Exactly the same action occurs with ray FG, and with all other rays incident upon the lens, refraction varying with the angle of incidence of each ray.

Image Formation

(47) All rays converging upon object X, in Fig. 34, that reach the surface of the lens will be refracted to meet again (be focused) at a point in image Y that corresponds to object X. At the image point the rays

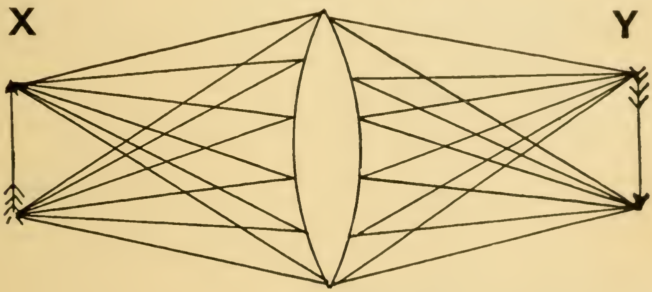


FIGURE 34

may spread over a larger or smaller area than they occupied at the object—the image being either magnified or diminished. Points X and Y are the conjugate foci points of the lens.

If object X is moved nearer the lens, image Y is automatically moved further away and magnified. If object X is moved further away, image Y is moved nearer the lens and reduced in size. If object X is moved up to the focal plane of the lens (separated from the lens by its focal length) Y is at infinity—that is to say, infinitely far away. If X is moved closer to the focal plane of the lens, Y is lost, the rays leaving the lens in diverging lines.

It is this law that is operative when the projection lens is moved backward or forward to focus the image sharply. In so doing the conjugate foci points are altered, though one of them only slightly. It must be remembered that one conjugate foci point (optic center of lens to film) is very short, while the other (optic center of lens to screen) is very long; therefore a very slight alteration of the shorter conjugate foci point will have a large effect upon the longer one, or vice versa.

Lens Correction

(48) All uncorrected lenses have spherical and chromatic aberration, as well as other faults. The aberrations may be eliminated by various combinations of glass and curvatures.

Focal Length

(49) The focal length of a simple lens is the distance from its optical center to the center of the image it

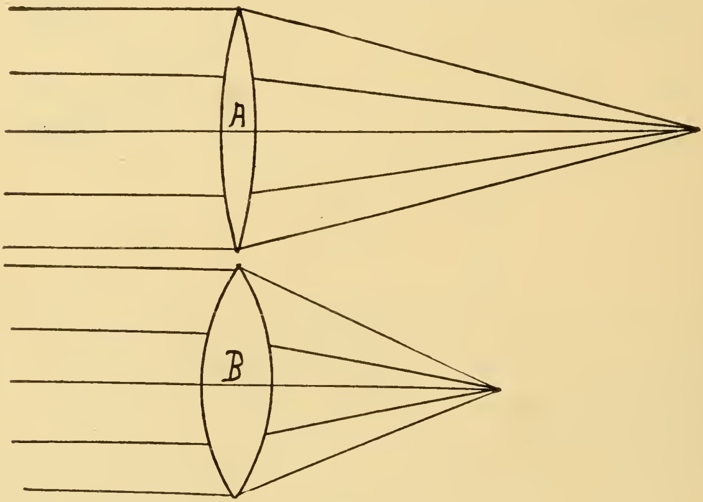


FIGURE 35

forms when the image is in sharpest possible focus and the object being focused is sufficiently distant so that light rays enter the lens in essentially parallel lines.

(50) The focal length of a lens is somewhat affected by the refractive index of its glass, but chiefly by the curvature of its surfaces. This is illustrated in Fig. 35, wherein we see two simple lenses in which the fault of spherical aberration has been disregarded. The actual performance of such lenses is shown in Fig. 36. It does not alter the focal length of the lens in any degree.

It is observed that the lens having the greatest surface curvature focuses parallel light rays nearest its plane.

Lens Curvature

(51) Each surface of such lenses as are shown in Fig. 35 are exact duplicates of the curved surface of a disc cut from a polished glass ball having a diameter equal to the focal length of the lens. For example, a 4½ inch diameter, 7½ inch focal length plano convex lens would be an exact duplicate of a 4½ inch diameter section cut from a polished glass ball 7½ inches in diameter and afterward polished on its flat side. Were the diameter of the ball 6½ inches, then such a disc cut from it would be a 6½ inch focal length plano convex lens. Were we to grind the flat side into concave form, the lens then would be what we term a "meniscus" lens.

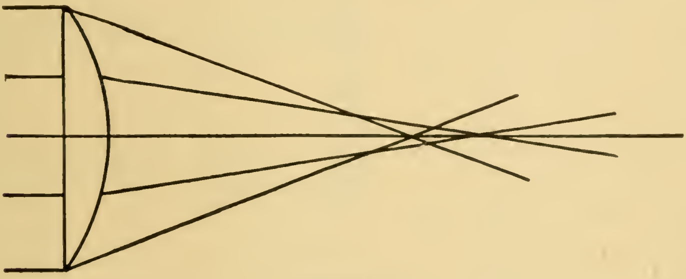


FIGURE 36

(52) Place two plano-convex lenses together and we have a bi-convex lens, examples of which are shown in Fig. 35. The refractive power of a bi-convex lens is double that of a single plano convex lens of equal surface curvature.

(53) Fig. 36 conveys visually the effect of spherical aberration. Examining it you will observe that rays passing through the lens close to its principal axis focus much further away from the lens plane than do the rays passing through its outer zones.

This effect is progressive from the principal axis to the outer margin of all simple lenses.

(54) Spherical aberration in simple lenses such as

are used for glass condensers has considerable value because it serves to "break up" the image of the light source, which never has even luminosity over its entire area. Spherical aberration has some value in preventing the image from being projected to the screen in the form of uneven illumination.

Lens Cannot Focus to a Point

(55) Unless the light source be infinitely small—a pinpoint, in fact—a lens cannot possibly focus light coming from it to a point. A lens focuses light rays to form an image of a light source or object and the image may be either smaller, larger or of equal size with the light source or object. (56) Stating it another way, rays are sent forth from every pinpoint of a light source, or from an object from which light is reflected. Rays from this pinpoint and from every other pinpoint of the light source or object are picked up by every section of a lens within their view which usually means its entire area. These rays are refracted by the lens and sent forward to a screen placed exactly at the other conjugate foci point of the lens, where they are refocused to a point which may, however, be larger than the point from which they come. Millions of these refocused points, each in its exactly appointed place, constitute an image of the object or light source from whence the rays emanate.

The Projection Lens

(57) The projection lens is known as a compound lens, which is a lens having more than one element. It has four lenses in fact, though two of them are usually cemented together with Canadian balsam. At the rear of the lens (end next the film) are two lenses, usually separated slightly by a spacing ring. At the other end of the lens barrel is the "front element," consisting of the two lenses cemented together. At a superficial glance they will appear to be one thick lens.

(58) Sometimes the Canadian balsam, with which the lenses are cemented together, will melt, producing a

streaked effect in the screen image. In such case the lens must be returned to its maker for repair. It is a job that cannot be done by the projectionist without danger of disturbing the lens corrections.

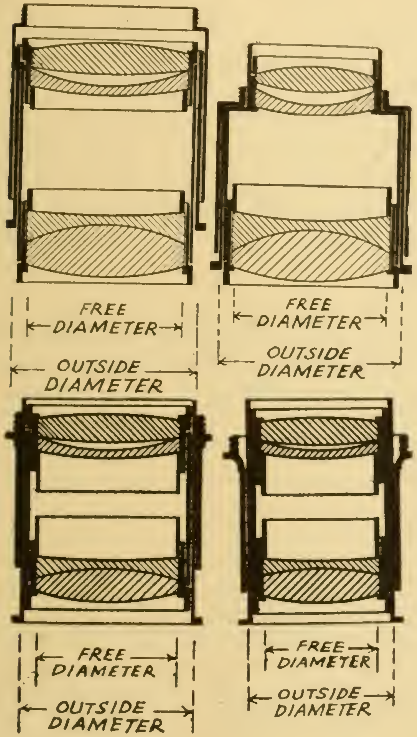


FIG. 37.—Sectional view of projection lens elements and their mountings.

(59) Some lens manufacturers employ a design in which the rear element (rear lenses) is the cemented combination, giving a long lens. The rear element is located much closer to the aperture than is usual in lenses having the front elements cemented. This design locates the cement considerably closer to the point of greatest heat concentration and consequently it is subjected to steady deterioration.

Repairing Lenses

(60) If one element of a projection lens is injured, the manufacturer can replace it. Send him the entire lens including the broken parts of the element to be repaired. (61) This will enable him to restore the lens to its exact original focal length.

(62) Odd lenses taken from old compound lenses have no value. They could be utilized only in building a new lens, but it would cost more than a good stock lens.

Ordering Lenses

(63) When ordering projection lenses supply the following data: (a) Kind of light source—Mazda,

straight arc, reflector type, high intensity or high intensity reflector arc. (b) Exact width of the picture at the center of its vertical length if there is any projection angle. (c) Projection angle. (d) Exact distance from the center of the screen to projection lens center. (e) Make of projector. (f) Width of projector aperture, in thousandths of an inch. The aperture width may be procured from the manufacturer of the projector, or it may be measured with the proper tool. If an exact measurement cannot be made, nor the lens sent, then tell the lens manufacturer the exact type of aperture used. (g) Specify lenses without jackets.

Range of Focal Lengths

(64) Projection lenses of the following standard focal lengths are carried in stock by manufacturers and by some dealers. Figures represent equivalent focus.

Quarter Size

Series I: 3, 3¼, 3½, 3¾; 4, 4¼, 4½, 4¾; 5, 5¼, 5½, 5¾; 6, 6¼, 6½, 6¾; 7, 7½; 8.

Half Size

Series II: 5, 5¼, 5½, 5¾; 6, 6¼, 6½, 6¾; 7, 7½; 8, 8½; 9.

Super Cinephor Lenses

Mounted in quarter size barrels: 2, 2¼, 2½, 2¾; 3, 3¼, 3½, 3¾.
Mounted in half size barrels: 4, 4¼, 4½, 4¾; 5, 5¼, 5½.

The above data—used merely as an illustration—covers Bausch and Lomb lenses only. Statement of focal lengths, etc., can be secured direct from other lens manufacturers upon request.

The so-called "quarter size" projection lenses are manufactured in focal lengths from 3 to 8 inches. E. F. Beyond 7 E. F. they may be had only in two sizes: 7½ and 8 inches E. F.

The new anastigmatic projection lenses, such as the Super Cinephor, are available in one-quarter inch focal length from 2 to 5½ inches E. F. The expressions "quarter and half sizes," of Series I and II, are no longer used in describing the Super Cinephor lenses. Every effort is being made in this line to approximate constant speed, as in the anastigmatic photographic lens design, in which the glass elements become larger but the same speed, so far as possible, is employed.

Matching Lenses

(65) Should you wish to obtain a projection lens to match the one you have, it is best to send the lens to the manufacturer. (66) If you cannot do that, then send him the precise width of the projector aperture opening, measured in thousandths of an inch; also the exact distance from the lens center to the screen at the center of the vertical height of the screen image (with no film over aperture); also the exact projection angle. Do not rely on lens markings as they have an allowable tolerance of error which makes them only approximately reliable.

(67) One lens manufacturer has an excellent method of marking his product. When a lens is finished, the E. F. is very carefully measured. If the E. F. is exact in focal lengths it is marked on the barrel as 5-inch, 6½-inch, etc. If the lens is a trifle more or less than the prescribed focal measurements, but is within plus or minus of one percent of the computed E. F., a plus or minus sign, as the case may be, is engraved in addition to the measurement. (68) All lenses marked without a plus or minus are considered as matched lenses, having even focus. The total difference in picture dimensions of a lens marked 6″— and one marked 6″+ would not in any case exceed 1 to 1.5 inches, which may be absorbed by the black border.

Light Loss By Reflection

(69) Optical engineers estimate that the light reflected from clean, well polished glass surfaces is from 4 to 5 percent at each surface where the light meets the surface perpendicularly. It is higher where the light meets the surface at an angle, and increases as the angle becomes more acute. Some optical systems have as many as ten glass surfaces through which the light must pass—each one of which reflects its quota of light. (70) There are heavy losses at other points—at the spot and at the rotating shutter, the latter eliminating approxi-

mately half the light at one swoop. Deposits of dust and scum gathered from the air also cause loss of light (by reflection) in exact proportion to the amount and character of the deposit.

It is easy to see how important it is to keep all lenses scrupulously clean and well polished. (71) Loss of light is not the only evil effect of dirty lenses. Deposits of dust and dirt disperse or diffuse and misdirect a portion of the light rays and as a result the lighter shades in the screen image are made still lighter and the blacks become a dirty gray. The picture, instead of being "snappy" is dull.

Cleaning Lenses

(72) Oil on a lens surface seriously injures the definition (focus) of the screen image. Oil, once deposited, spreads around. (73) A slight finger mark, so faint it cannot be seen by looking through the lens, may blur definition. (74) Such marks usually may be seen by looking at the glass surface sidewise.

(75) There are many lens cleaning preparations on the market, but best of all is a soft cloth and a mixture of half clean water and half grain alcohol. Do not use denatured alcohol as it leaves a scum on the glass. Clean the lens when it is cold. Be careful not to touch the lens with your fingers after cleaning it.

(76) Lenses should be examined at least once each day. (77) Mirrors or condensing lenses should be cleaned each morning while they are cold.

(78) At regular intervals, lenses should be disassembled, the coating on the interior of their barrels examined and the lens surfaces cleaned. (79) The interior coating of the barrel is dull black to prevent reflection of light. (80) If it wears or peels off so that the metal shows, it should be recoated immediately, using coach painters' black thinned with turpentine. In reassembling lenses, each element must be replaced with its heaviest curvature toward the screen end of the lens.

(81) One lens manufacturer tapers the various lens edges so that they cannot be replaced wrongly. Some-

thing of this sort should be done by all projection lens makers. (82) Projectionists who have lenses in which the elements can be wrongly assembled will do well to secure a bottle of waterproof draughtsman's ink, black or red in color, and as they disassemble the lenses for the first time, put a small spot of ink on the face of each lens just at its outer edge on the screen side. The spot should remain indefinitely. The ink or other mark must be near enough the lens edge to be hidden by the retaining ring.

(83) Exercise care and patience in disassembling. The retaining parts have very fine threads and are for the most part rather light. They may be bent out of shape quite easily. Do not attempt to force them by using a screwdriver point or other heavy instrument. Unthread with your fingers if it is at all possible to do so.

(84) When reassembling clamp each separate lens into its retaining mount snugly, but be very careful not to set the holding element up too highly. If you do, it will make it difficult to disassemble the lens again when necessary. It will be sufficient to set the ring up so that the lens does not rattle audibly when shaken. Screw the retaining mounts into the barrel as far as they will go. Failure to do this will disturb both the E. F. and the corrections of the lens.

Loss Through Absorption

(85) Glass used in modern projection lenses absorbs but a small percentage of the light as it passes through the body of the glass itself. Absorption of good crown glass is given as 1 to 1.5 percent per centimeter (.3937+ of an inch) of distance covered by the light. Flint glass absorption is just a little higher. (86) Poor quality glass may absorb as much as five percent of the light per centimeter of thickness. Since condensing lenses of the ordinary plano convex 4.5-inch diameter type are thick, it is apparent that a condenser lens made of good grade glass is to be preferred to one of poor quality glass which absorbs light excessively.

Barrel or Pincushion Distortion

(87) Barrel distortion in a lens causes it to project a straight line in the form of a more or less pronounced outward curve. Pincushion distortion causes the lines to bend inward. (88) Following is a test for either fault. New lenses should be subjected to it immediately.

(89) Open the projector gate and project white light to the screen. Stretch a cord lightly along the edges of the light. If the edges are straight there is no barrel or pincushion distortion. If the edges bend outward there is barrel distortion. If the edges bend inward there is pincushion distortion.

Testing for Flatness of Field

(90) It is very easy to test a lens for its ability to produce flatness of field (sharp definition of "focus") all over the screen surface, yet apparently few projectionists know how to do it.

First, prepare a light wooden frame two or three feet square. Stretch white paper or cloth over it tightly. Select a film scene in which you are certain the photographic focus is sharp. Project it and sharpen focus as critically as possible at the screen center. Examine one corner of the screen image carefully. If the definition at the screen center and corner is equally sharp, then the lens has passed the test for flatness of field. But if the definition at the corners is less sharp than at the center, then hold the small screen in the proper position in relation to the light beam and advance it slowly toward the lens, while a second person observes the definition from the front. When a point is reached where the definition at the corners is as sharp as the screen center, the point represents the outer end of the arc of a circle that would touch the screen surface at its center. It represents the curvature of the screen surface necessary to secure sharpness of definition (focus) over its entire area. It therefore shows exactly how much the lens under test fails to produce flatness of field.

Why and Wherefore of Focusing

(91) From every pinpoint of the film photograph posed over the projector aperture, millions of diverging light rays go forward in the form of a cone, the taper of which is dependent upon the focal length of the condenser or reflecting mirror and its distance from the aperture. (92) It is the function of the lens to collect these rays from every pinpoint of the photograph, and to refract them so that they will converge and focus at similarly placed but enlarged points upon the screen. The film represents one conjugate foci point of the projection lens, the screen the other. (93) If the distance of the lens from the film is altered in any degree by means of the focusing screw, or by other means, the definition or focus of the screen image is changed.

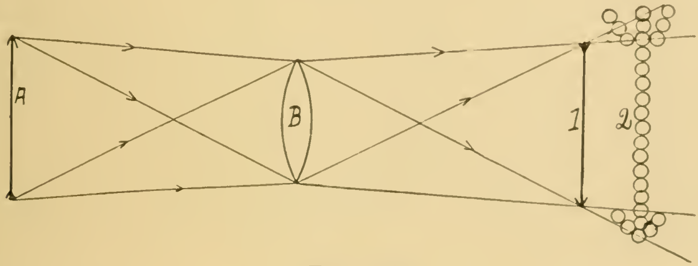


Figure 38

(94) In Fig. 38, we find an explanation. A, being the film, B the projection lens and 1 the screen, it is observed that at 1, the point of focus, the rays emanating from the film photograph meet the cross. If the screen were at 2 instead— and not at 1—the rays would not focus at 2 unless the conjugate foci points were altered. On this plane each point would appear as a circle and the whole image would be badly blurred. When the screen image is blurred it indicates that the rays are focused at a point or plane either before or behind the screen surface. The lens must then be moved slightly backward or forward, altering the conjugate foci points so that the rays focus exactly at the screen surface of the plane.

(95) Depth of focus is definitely a physical condition.

(96) It is in exact proportion to the speed (diameter) of a lens and its focal length. (97) All lenses having equal quality of correction, equal focus and equal diameter will have exactly the same depth of focus.

Altering Lens Focal Length

(98) It is impossible to alter the E. F. of a lens by lengthening or shortening the distance between its front and back factors—by lengthening or shortening the tube in which they are mounted—without, at the same time, destroying its maximum efficiency. It is a bad practice.

Picture Size and E. F. of Lens

(99) Any lens will project a picture any practicable distance, but (100) a lens can project a picture of given dimensions at one, fixed distance only. If it projects further, the picture dimensions will be increased and vice versa. Any alteration of projection distance automatically alters the working distance of the lens. (101) The greater the E. F. of the lens the longer will be its working distance—distance of the surface of the rear lens to the aperture. Moving one conjugate foci point further from the lens automatically moves the other closer to the lens.

Measuring Focal Length

(102) Due to spherical aberration and other faults of simple lenses, the projectionist cannot measure their focal length accurately unless he uses a gauge for measuring lenses in diopters. With this instrument, focal length in inches is easily calculated. (103) He may, however, measure their focal length for all practical purposes by another means—crude but sufficiently accurate.

(104) To measure the focal length of a plano convex lens proceed as follows: Select an open window from which some object not less than fifty feet nor more than one hundred feet distant is visible. To the wall opposite the window pin a sheet of white paper. Hold the lens with its flat side toward the screen and parallel with its

surface. Focus the distant object as sharply as possible on the paper screen, while an assistant measures the distance from the flat side of the lens to the screen. Reverse the lens, holding its convex side toward the screen and the flat side parallel with the screen's surface. Again focus the object sharply and measure the distance from the flat side of the lens to the screen. Add these two measurements and divide by 2. The result will be a close approximation of the focal length of the lens.

(105) Bi-convex lenses may be measured the same way. Focus a distant object sharply on the paper screen and measure from the center of the lens edge to the screen surface. That will be the focal length of the lens, provided the lens has been held parallel with the screen surface.

Focal Length of Simple Lenses

(106) Be sure the lens is perfectly clean. Hold it parallel with the screen so that its edge all around is equi-distant from the screen surface. Focus an object no less than 50 feet away. An object 100 feet or more away is better since it allows the light to enter the lens in essentially parallel rays which leads to more accurate conclusions. The room should be as dark as practicable when making the measurement, because too much light makes it difficult to judge the sharpness of focus.

Measuring Working Distance

(107) To measure a working distance, first focus the picture as sharply as possible on the screen. Stop the projector, remove the film and measure the exact distance from face of the tracks upon which the film rests in passing through the gate, to the first surface of the lens. If the uncoated side of the film is next to the aperture the thickness of the film must be added for exact accuracy. This measurement is the working distance often wrongly referred to as "back focus."

Measuring Equivalent Focus

(108) This is seldom necessary but easy to do. Use two sheets of black or dark colored paper a few inches

square. In one sheet cut a hole one inch square or smaller. Trace the outline of this hole on the other sheet. Mount the opening in the dark paper over a hole cut in a large sheet of opaque wrapping paper. Next suspend the wrapping paper over an open window and with the help of two assistants, focus the lens on the opening until its image exactly fills the space within the traced outline on the second black sheet. Measure the exact distance from wrapping paper to the second black sheet. Divide the sum by 4 and the result is the E. F. of the lens.

Working Distance and Lens Diameter

(109) When using certain types of condenser, working distance and lens diameter become important items in obtaining even screen illumination and in avoiding waste of light. The projectionist may determine whether or not the condition is correct with a little effort.

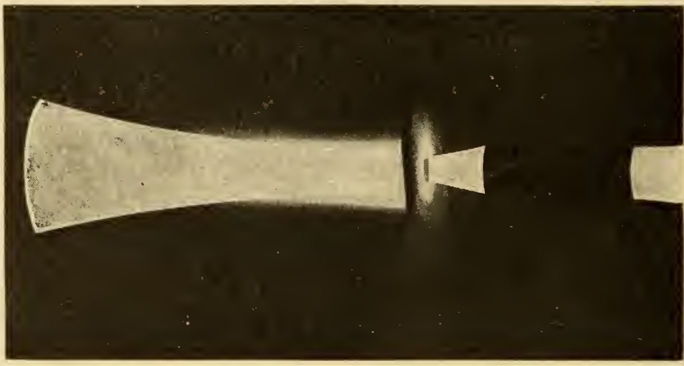


Figure 39

(110) Open the projector gate and remove anything which obstructs the view of the aperture and the lens. Project a white light to the lens and blow smoke into the mechanism casing. Instantly the light beam will become sharply visible and its exact diameter where it meets the lens may be observed. Do not run the mechanism during the operation as air disturbance by the projector shutter will make the view of the beam less distinct. Hold a white paper or cloth at the rear end of

the lens and observe the beam diameter that way if you prefer.

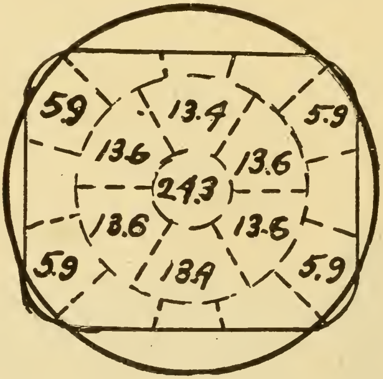
(111) If a plano-convex condenser is used the beam will be as in Fig. 39. It may or may not all enter the lens. (112) If it does not, a lens of larger diameter is needed although other considerations may make it impractical. A longer focal length converging condenser lens may increase the distance between the condenser and the aperture, and thus reduce the spread of the beam beyond the aperture. Increasing the focal length of the condenser will automatically increase the distance of the light source from the collector lens, and thus set up a loss which may neutralize any gain, but any reduction of the spread of the beam between the aperture and lens will tend to make the screen illumination smoother even if the beam is not all entering the lens.

Figure 40

In Fig. 40, a photograph with light made visible by smoke, we see how the light beam overlaps the lens.

(113) Any projectionist may ascertain for himself by means of a simple, convincing experiment whether this sets up uneven light distribution on the screen. Secure a small sheet of stove pipe or other thin flat metal. Cut out a strip about three inches long the width of a film. On its surface lay out two frame lines the same shape and size as those on film. Lay this on a freshly sawed block of wood, end-of-grain side up, and with a punch filed to a sharp point, punch a small hole exactly in the center of one of the "frames" and near one (either) corner of the other.

Now place the metal strip over the aperture with the center hole in the center of the aperture. Centering the hole is important, though if it is within 1/16 of an inch of the center it will do. Block up the automatic fire shutter and project a white light through the hole. Blow smoke into the tiny light beam (projector is not running) and you may see just what area of the lens the beam covers. Probably all of it will be found to enter the lens, which, of course, indicates that all the light passing through the center zone of the film enters the lens and consequently the central portion of the film is fully illuminated on the screen.



Exact Size and Shape of Ray Three Inches from Aperture When Condenser is 18 Inches from Aperture.

Zone	Area	Avg. F.C.	Lumens	% Total
1	.0077	24.3	.19	10.8
2	.062	13.5	.86	49.2
3			.70	40.0
		Total	1.75	100.

FIGURE 41

Now place the other "frame" over the aperture, so that the hole will be at one corner of the aperture instead of at its center. Again blow smoke and observe the condition. If the whole cone of light enters the lens, well and good. If it does not, then it is plainly evident that the light incident upon the outer zones of the film does not all enter the lens and hence there is unevenness of screen illumination. Fig. 41-A is a graphic illustration of the experiment.

Fig. 41 illustrates the fact that the light beam between the projector aperture and the lens does not always have an even light intensity. It sets forth the intensity of light at various sections of the beams, as measured for the BLUEBOOK recently by Eastman engineers. Light values have changed widely, but light distribution, as shown in Fig. 41, has not altered in any appreciable degree.

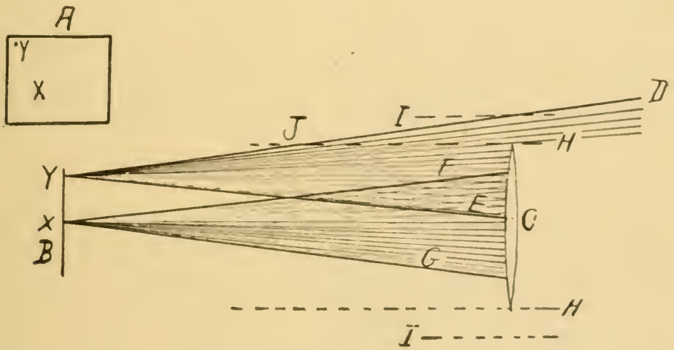


FIGURE 41A

Observe that in the center zone the light intensity is 24.3 foot candles. Because the total area of the zone is very small, the light flux therein represents only 10.8 percent of the total, regardless of the fact that the small zone is very brilliant.

Examining zone 2 we see that the light intensity drops to about 13.6 foot candles, but nevertheless, because of the larger area, zone 2 supplies almost five times the total light—49.2 percent more than zone 1, —while zone 3, which drops down to 5.9 foot candles, supplies 40 percent of the total illumination.

A very interesting point here is that whereas these are the measurements when the converging lens is 18 inches from the aperture and the projection lens at a 3 inch working distance, when the converger is the same distance from the aperture, but the projection lens at

7 inch working distance, the zone readings average: center 13 c. p., zone two 10.1, while zone 3 holds up to 5.6, which is almost its value under the other condition.

Failure to get the entire light beam into the projection lens means very real loss of light. Long focal length lenses generally provide more even screen illumination than the shorter focal length ones.

In Fig. 40 we see a normal light beam from a 2-lens plano-convex condenser. Note the circle of light on the back of the aperture plate. It is caused by light reflected from surfaces of various elements of the projection lens, each of which adds its quota. When the picture was made the lenses were very clean. Had they been fogged with dust or dirt, reflection loss would have been increased in proportion to the amount of fogging.

Projector Optical Train

(114) The projector optical train consists of two entirely separate elements joined together more or less efficiently. Efficiency of the jointure depends upon the amount of skill with which it is made.

(115) First, the condenser or mirror which collects light from the light source, bends or reflects its diverging rays and concentrates it upon the cooling plate and aperture of the projector mechanism. Second, (116) the projection lens, which receives the rays passing through the film photograph and focuses all their millions of numbers upon their appointed spot in the screen image.

Light leaves the light source in diverging rays (Figs. 30 and 38), which move forward until the face of the collector lens or curved mirror is reached. (117) The light source and collector should be as close together as possible.

(118) Examining Fig. 42, the reason for minimum distance becomes self-evident. We see that it would require a collector 7.25 inches in diamter located 4.5 inches from the light source to collect the same amount of light available to collector 4.25 inches in diamter only 2.5 inches from the light source.

It is thus evident that any unnecessary distance of the light source to collector involves heavy light loss.

LIMITATIONS GOVERNING DISTANCE

(119) Limitations vary with the character of the light source. With mazda it is almost wholly optical, the only other limiting factor being the diameter of the mazda lamp globe, which itself prevents the light source (filament) from being advanced nearer to the collector lens by more than half its diameter.

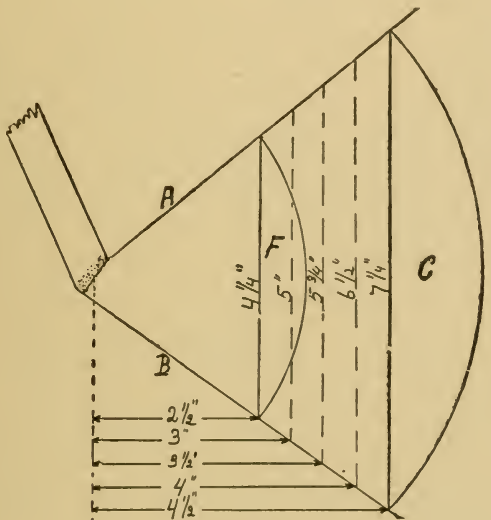


FIGURE 42

The optic requirements for the distance from the light source to the collector demand the beam of light to spread sufficiently to form a "spot" of sufficient diameter at the required distance from the converging lens to the projector aperture. As the light source is brought nearer the collector lens of a condenser, or the surface of a curved mirror, such as is used in projection, the light beam on the opposite side of the condenser or in front of the mirror or condenser converging lens is increased in diameter.

Where the light source is an electric arc, the two limiting factors of distance are (a) enough distance to set up the reqiured beam diameter at the projector aperture, and (b) heat. Heat is the main governing factor where high power electric arcs are used; often a more satisfactory optical condition might be had with the collector closer to the light source but heat will not permit it.

(120) Condenser lenses have a thin edge and a thick center and consequently they heat and expand much more rapidly at their outer zones than at their center, which sets up a condition of great strain, (121) particularly if the light source is a powerful one, or has a heavy tail flame. A heavy tail flame creates an extremely high temperature at one point—the upper edge of the collector lens—and cracks the lens if the distance of the light source to the lens is too short. (122) This may be controlled somewhat by interposing a small sheet of mica between the outer portion of the flame and lens, but the mica must be out of range of the light cone incident upon the lens.

The distance of the light source to the lens may be increased by installing a converging lens (a plano-convex condenser) of longer focal length. This cannot be done with a parabolic combination. (123) The plano-convex condenser collector lens should always be 6.5-inch focal length. The converger should have a focal length sufficient to set up the proper condition at the aperture when the light source is at the minimum permissible distance from the collector.

Lens Pitting

(124) Pitting is caused by particles of incandescent matter from the light source striking the lens and ruining the polish at point of impact. As a consequence the light that strikes a pitted spot is diffused and very largely wasted. Pitting may be decreased or stopped altogether by lengthening the distance from the light source to the lens, but that entails heavy loss of light (see Fig. 42) and the "gain" is likely to prove a loss. With increased distance the lens will not have to be

renewed so often, but current bills will be bigger—or as an alternative screen illumination will be decreased.

The Collector

We now arrive at the collector, which may be either a glass lens or a curved mirror. (125) If it is a lens (a plano convex condenser) it should be a 6.5-inch focal length lens, (126) with the focal length of the converging lens sufficient to provide the necessary spot diameter at the aperture and a minimum distance from the light source to the collector. This applies only to the plano-convex 2-lens condenser. (127) The lenses are placed with their curved surfaces together for two reasons. First, were the collector lens placed with its curved surface toward the light source, the reflection from its outer zones would be very high—in fact, if the distance from the light source to the lens is short, the reflection at its outer zones would include almost all the light incident on these zones. Second, with its curved surfaces together, opticians tell us there is less spherical aberration than when mounted the other way.

Spacing Condenser Lenses

(128) Condenser lenses should be as close together as possible without actual physical contact. Contact would transfer heat from the very hot collector to a single spot on the relatively cool converging lens. (129) As Fig. 43 shows, the collector does not send forward a parallel, but a diverging beam. The actual separation need be no more than 1/64 inch but it must be enough to prevent actual physical contact.

The Converging Lens

With a 2-lens plano-convex condenser, use a 6.5-inch focal length collector in conjunction with a converging lens of sufficient focal length to give the required spot diameter at the desired distance. (130) The spot diameter will be dependent upon the focal length of the combination, when the distance from the converging lens to aperture has been fixed.

(131) Ascertain the minimum possible distance the light source may be carried from the collector lens or the mirror and the minimum spot diameter that may be maintained without discoloration of the screen illumination. Select a condenser that will establish these conditions.

The Mirror Collector-Converger

(132) Mirrors are used to collect light either to project it in a parallel beam back to a large-diameter, thin condensing lens, which in turn converges the light to a spot at the projector aperture, or to collect the light and reflect it directly back in a converging beam to the projector aperture. They are available in three forms:

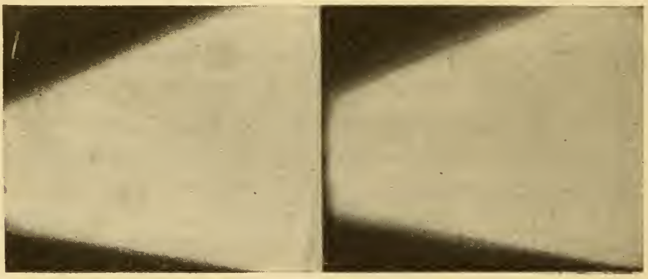


Fig. 43.—Beams from 6.50 inch and 7.50 inch focal length lenses.

spherical, parabolic and elliptical. In Fig. 44 the nature of the three surfaces is indicated in exaggerated form.

(133) In Fig. 36 we see that in an uncorrected lens the quality termed "spherical aberration" causes the rays from a light source of considerable area that are incident upon the outer zones of the lens, to focus closer to the lens than those incident upon its more central zones. This effect becomes progressively greater from the optical axis of the lens outward. (134) All spherical mirrors have this fault (135) which may be corrected by a very slight departure from the true spherical curve along the lines shown at A and B in Fig. 44. (136) It is this departure that constitutes the parabolic and the elliptical mirror.

Knowing that the angle at which a light ray meets a reflecting surface (angle of incidence) is always equal to the angle at which it is reflected therefrom (angle of reflection), it will be understood readily that if the surface of the mirror or a lens is accurately curved along the lines indicated by curves A and B in Fig. 44, the rays from the outer zones will spread sufficiently to focus at the same plane as those from the central zones. Thus spherical aberration will be "corrected."

Fig. 44.—The elliptical and parabolic curves are exaggerated. In actual practice they are invisible to the eye. A is parabolic; B is elliptical; C is spherical.

(137) In practice spherical aberration forces rays that normally should pass through the aperture to fall wastefully upon the cooling plate and forces other rays that pass through the aperture to fall either entirely outside the lens, or upon the wrong spot on the lens.

(138) On the other hand it is true that spherical aberration breaks up the light source image, causing its high and low points of illumination to merge together. Today, since only the light from one high intensity carbon requires breaking up, spherical aberration may be considered a harmful characteristic in a lens.

(139) If properly installed and adjusted, a mirror will collect a much wider angle of light per unit of electrical energy (calculated at the light source) than a 4.25 inch free diameter condenser collector lens is able to do, and for the following reason:

Fig. 45 shows the face of a 4.25-inch free diameter plano-convex collector lens. Observe that when the light source is located 3 inches away it is able to collect but a 70 degree angle of light. The rest falls outside the lens. Here degrees represent a section or arc of a circle, the center of which is, at the light source, a curve representing the circumference passing through both edges of the lens. The 70 degrees do not represent the total light picked up since in the case of either lens or mirror the strongest light goes straight out from the face of the crater floor.

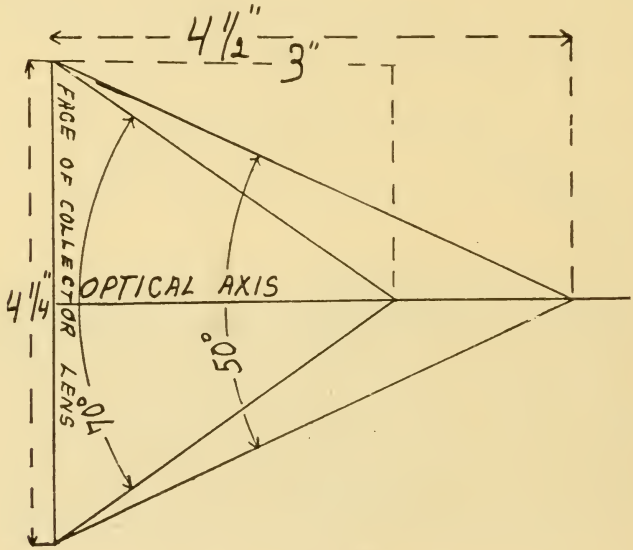


FIGURE 45

Were the lens located 4.5 inches from the light source it would intercept but a 50 degree angle of light, the two distances representing the minimum and maximum distances from the light source to the lens or mirror.

(140) Turning next to Fig. 46, we view a mirror collector 7.5 inches in diameter, the light source located 3.3 inches from its vertex (center). It will intercept an angle of light of 120 degrees. If we increase the mirror diameter to 8 inches and locate the light source 4.5 inches from the mirror vertex, it will still intercept a 100 degree angle of light, as against the smaller angle available to the 4.25 inch free diameter glass collector under analogous conditions. Even if we use a 6⅝ inch diameter mirror, with light source 3.75 inches from its vertex, we can collect approximately a 95 degree light angle.

(141) From all this it is evident the mirror is a far more efficient collector of light than the 4.25 inch free diameter 2-lens plano-convex condenser. This is by no means its only advantage. Most of the reflector type lamps use no condenser at all, the mirror reflecting the collected light directly back and converging it into the "spot" at the cooling plate-aperture. It eliminates the very heavy light loss due to reflection from the four glass surfaces encountered in 2-lens condensers, in addition to the loss sustained in the absorption of light by the glass itself.

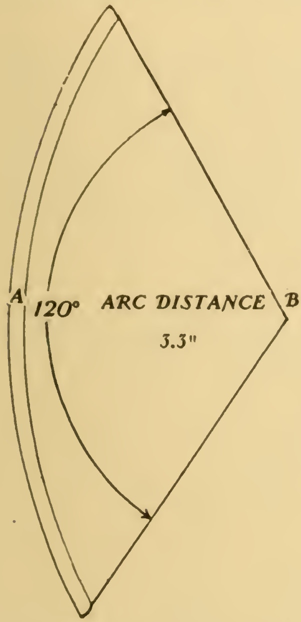


Fig. 46. — Showing mirror diameter 7.5 inches parabolic curve.

The loss on account of reflection will remain high if the lens surface is not kept perfectly clean.

As against this high efficiency in light collection and delivery at the projector aperture, the lens in the reflector type lamp, using a thin condenser, wastes (mostly by reflection) about 12 percent of the rays, and the mirror itself wastes (again largely by reflection at the glass surface) about 8 percent; the remainder is sent forward to the cooling plate and aperture.

(142) The mirror offers less reflection and loses less light through absorption but it creates a very hot spot at the aperture, there being no condenser to absorb any portion of the heat rays. Whenever a condenser is used, thin and of wide diameter, the aperture heat is somewhat reduced because the lens absorbs and radiates about 15 percent of it.

(143) When the rotating shutter was located on the screen side of the projection lens it in no wise reduced the spot heat produced by reflector type equipment. But

when it was shifted to a position between the light source and the aperture it cut the heat down approximately 50 percent. The mirror hot spot, therefore, is no longer an important point. Rear shutters create a strong current of air which has a very decided cooling effect at the aperture.

(144) In choosing between the mirror collector and the 2-lens glass condenser remember that the mirror, of the two, is the more efficient collector of light. It is slightly deficient because of its high aperture temperature but it is still to be preferred except where a straight high arc is used which must have a 2-lens glass condenser.

Mirror Action

We will now try to make clear the action of curved mirrors used in high and low intensity reflector type

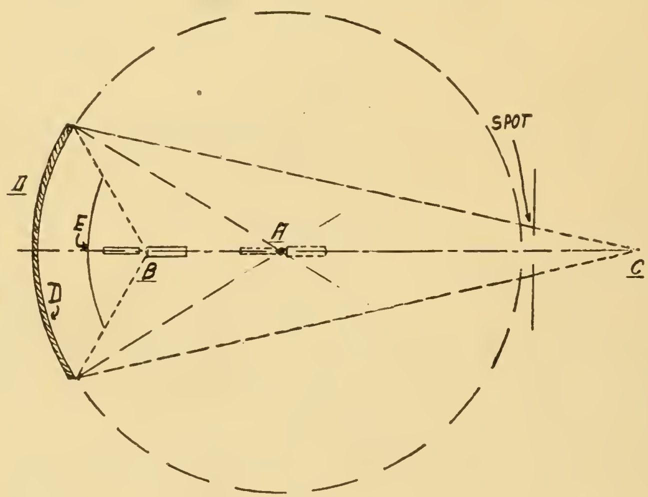


Figure 47

lamps. Fig. 47 shows a curved mirror and projector aperture, with the light source AB in two positions. The mirror being spherical, its curvature corresponds exactly to that of the broken line curve, the center of which is at A.

(145) Now if light source A were a point (having

no area), all rays reflected by the mirror surface would focus at point C. But a light source is not a point; it has considerable area. Therefore rays from its outer margins meet the mirror surface at a slightly different angle than those coming from its center. This has the effect of producing what we call "spherical aberration," since the difference of angle of incidence will cause rays striking the outer zones of the collector to focus closer than the rays from the central zones. If you lay the lines out on paper you will see that while the rays from the outer margins of the light source to the center of the mirror or lens will be affected, still the rays to the outer zones of the collector will be affected very much more. It is wholly a matter of the angles at which rays from the light source meet the different zones of the mirror surface.

The angle of incidence is always exactly equal to the angle of reflection. In a spherical mirror all points of the surface cannot correspond precisely at the same angle to points on a light source and therefore the rays reflected by the different zones of the mirror will focus at different distances from its reflecting surface.

(146) This condition causes spherical aberration. It can be corrected, partly, by tilting the outer zones of the mirror slightly backward which gives either a parabolic or an elliptical effect.

(147) It is evident that if light source A, in Fig. 47, was moved closer to the mirror, to B, the angles of incidence and reflection would be so altered that the beam would no longer focus at C, but much further back. It is this action that explains the reduction of enlargement of the spot diameter as the light source is moved nearer to or further away from the mirror.

Selection of Mirror Collector

(148) Silver has the highest power of reflection, and polished glass the smoothest, closest grain surface of any substances suitable for mirrors. Therefore they yield the highest possible accuracy and optical efficiency in any product designed for the reflection of light.

(149) Silver will tarnish when exposed to air. To overcome this tendency it is placed upon the polished back of a curved glass mirror and (150) upon it is laid a coat of a heat resisting, non-porous covering called "mirror backing." The glass itself, of course, protects the silver on the other side.

In mirror reflectors of the parabolic or elliptical type (151) the light source must be located at a certain fixed distance from the mirror surface, and the mirror surface in its turn a certain fixed distance from the projector aperture. Any departure from these distances, particularly of the distance from the light source to the mirror, will mean loss in efficiency. (152) The distance from the light source to the mirror vertex is called the "mirror focus." (153) The distance from mirror vertex to the aperture is called the "mirror working distance."

(154) For best results mirrors must be operated at exactly the correct focus and working distance. (155) Distances are not the same for mirrors of different focal lengths. (156) An error of less than one millimeter in mirror focus distance is a very serious matter. It is therefore well to proceed with great caution in making changes in the adjustments of the mirror, especially when changing mirror focal lengths. Where slight alterations may produce such serious results it is a much better plan to follow the manufacturers recommendations and instructions very carefully, varying from them only when you are positively certain that results will be improved. You can secure instruction books freely by writing to the manufacturers.

(157) For low intensity lamps, it is advisable to use mirrors made of high grade optical glass which will not crack readily from heat if correct distances are maintained. When using the reflector type high intensity lamps, however, the mirror must be of high grade, heat resisting glass (pyrex, for example), if excessive breakage is to be avoided.

Care of Mirrors

(158) Mirrors cannot function efficiently unless the

silver reflecting surfaces remain whole and untarnished and the front (glass) surfaces are always clean and undamaged. (159) Low intensity lamp mirrors should be wiped clean and polished with a clean, soft cloth at least once each day, and not less than twice each day where performances are continuous.

(160) In the morning, when the mirror is cold, polish it thoroughly with a clean, soft cloth. An excellent cleaning fluid is pure grain alcohol and clean water, mixed half and half. Dampen a cloth with it, wipe the mirror face and polish quickly and thoroughly. Do not use denatured alcohol as it contains chemicals that leave a thin film on the glass.

(161) Where the flaming type high intensity is used the mirror surface should be wiped with a bit of cloth wet with the water-alcohol mixture, and polished thoroughly, using only a clean, dry, soft cloth. Afterward wipe its surface with a clean, soft cloth immediately before striking the arc for each run. This also holds true for the a. c. arc.

(162) Once each week and daily in continuous theatres, regardless of whether you have high or low intensity, remove the mirrors and wash them thoroughly with strong soapsuds. Rinse the soap off and polish them with a soft, clean cloth or soft tissue paper. Some projectionists do this every morning, which is a good practice. Do not get the back of the mirror wet.

Tarnished Mirrors

(163) Under the action of heat, the silver reflection surface will tarnish in time. When this occurs the mirror should be returned immediately to the manufacturer, either directly or through your dealer, for resilvering. (164) If the mirror is pitted or scratched, and the marks are not too deep, the mirror can be ground off and made as good as new at less than the cost of a new one. But if the pit marks or scratches are deep, regrinding is too costly and the mirror should be replaced.

(165) Do not continue a badly scratched or pitted mirror in service. If you do you will waste more light (power) than a new mirror is worth.

SCREENS

1. What are the items of basic importance in a screen?

Reflecting Surfaces, Etc., page 146

2. What does wasted light represent?
3. What two chief items are involved in consideration of reflection power?
4. Is the amount of light reflected in one direction necessarily any indication of the amount reflected in other directions?
5. What affects reflection power?
6. Do all pure white surfaces have equal reflection power?
7. Why is loosely woven white cloth a poor reflection surface?
8. How may fine, hard-twist white cloth be made a good reflection surface?
9. Is white lead paint a good reflection surface and how may its reflection power be improved?
10. Is kalsomine a good reflection surface?
11. What are the chief objections to metallic screen surfaces?
12. Name the chief points for and against glass bead screens.
13. Can a glass bead screen be cleaned to restore its reflection powers in full?
14. For what condition is the glass bead screen or other specular surface best suited; for what conditions are ill suited?
15. Is reflection power of all screens reduced at each cleaning?
16. Upon what points should exhibitors and projectionsist concentrate when purchasing a new screen?
17. Is the percentage of reflected light a varying element?
18. What causes variation?

Testing Reflection Power, page 149

19. How may loss in reflection power due to age or accumulation of dirt be tested in a thoroughly practical manner?
20. Are statements that a screen will reflect light in excess of 100 percent correct?

21. What does Table No. 6 show?
22. Should exhibitors accept unsupported statements regarding the reflection power of certain substances?
23. What is the relative reflection power of certain substances?
24. How would you analyze Table No. 6?
25. What screen attribute is more important than the amount of light reflected?

Light Tone, page 153

26. May the tone or color of light be affected by a screen surface without tinting the surface?
27. What kind of screen surface should be selected when Mazda is used?
28. What is the problem when a high power arc light source is used?

Type of Surface, Side Angle Distortion, page 153

29. What is the difference between a "specular" and a "diffusing" screen?
30. What decides which type of screen surface is needed in your theatre?
31. What knowledge is useful in the selection of a proper screen for a particular theatre? How may such knowledge be obtained?
32. Why will those seated at a "heavy" side angle to the screen see objects at less than their true width and seemingly abnormally tall?
33. What is the one possible remedy for this condition?
34. What screen is best where "heavy" viewing angles are involved?

Screen Mounting, page 155

35. What is the best screen mount?

Cleaning Screens, page 156

36. Is it true that any screen surface can be cleaned to restore 100 percent of its reflection value?

37. Do all screen surfaces except glass undergo chemical changes?
38. Should a guarantee accompany each new screen, covering the feasability and cost of recoating its surface?

Perforations, page 156

39. Approximately how many perforations are there to each square foot of an average perforated screen?
40. How much reflection surface and picture detail is eliminated by perforation?
41. Is there any valid reason for the use of perforated screens?

How to Obtain Viewing Angles, page 157

42. How may viewing angles be calculated?

Perforated vs. Solid Screens, page 158

43. Name the admitted objections to perforated screens.
44. What objections are there to too much or too little distance from seats to screen?
45. What should be the minimum distance from front seats to the screen?
46. How high should the picture be above the floor?

Picture Size and Light Demand, page 160

47. What point is immediately involved when the size of the picture is under consideration?
48. What effect has picture size on illumination?
49. What effect has picture size upon magnification?
50. How may magnification be calculated?
51. What effect has bigger picture sizes upon visibility of defects in photography?
52. What relation is there between the size of the picture and the brilliancy of illumination?
53. What relation is there between the size of the picture and its surroundings?

54. Except under unusual conditions what maximum picture size is best?

Tinting, page 161

55. Has screen tinting any real value? Are there valid objections to it?

Location and Surroundings of Screen, page 161

56. What should be the position of screen on stage?
57. What should be done to the stage floor in front of the screen?
58. What is important with regard to the immediate surroundings of the screen?
59. What constitutes the best screen border?
60. Are theatre screens ever evenly illuminated over their entire area?
61. Is it possible for exhibitors to apply a screen coating that will have excellent reflection powers?
62. Can a "homemade" screen surface be more efficient than a costly one that is purchased?
63. What is the best method of mounting screens?
64. Do properly prepared paints and kalsomines have good powers of reflection and diffusion?
65. What is the correct method of painting a screen surface, using raw cloth as a base?
66. How would you proceed to make a kalsomine surface screen?
67. Can a perforated screen be recoated by the exhibitor?
68. What must be avoided in recoating perforated screens?
69. What test should be made before starting to paint an old screen surface?
70. If the paint will not adhere to surface what should be done?
71. By what means is it possible to free the perforations of surplus paint or kalsomine?
72. What is the best method of applying paint or kalsomine to a screen?
73. What screen image sizes have been suggested by the S.M.P.E.?

74. What should be the level of illumination in theatre auditoriums?

75. What is the effect of light other than that from the projection lens falling upon the screen?

76. Should any light other than that from the lens be permitted to reach the screen?

77. What is a "glare spot"?

78. How may viewing comfort be increased from any distance?

CHAPTER VI.

SCREENS

(1) From the audience point of view the function of a screen is to reflect the projected picture in the most pleasing manner. Technically this calls for a number of things: (a) It must deliver to the audience the largest possible percentage of the light incident upon its surface; (b) it must do this with a minimum fadeaway at side angles and (c) it must oppose a minimum interference to sound volume and distribution.

These are characteristics that should be required when purchasing a new screen to assure a full measure of efficiency during its life in the theatre.

Reflecting Surfaces

(2) The efficiency of the screen in reflecting light is of great importance. If it fails, either the beauty of the picture will be damaged or it will require increased power (light) consumption to give the picture full screen values. This greater power consumption will soon assume sizable proportions in the theatre's overhead expenses.

(3) In selecting a screen, bear in mind two distinct factors—one, the total percentage of incident light reflected and two, its distribution. (4) Measurement in a single direction is no proof of the total reflection power of a surface. A screen surface that has high efficiency in a 25-foot wide auditorium might be extremely inefficient in one 50 feet wide.

(5) Reflection power is affected by (a) character of surface, (b) color, (c) cleanliness, and (d) its age. The surface reflecting the greatest percentage of incident light, other things being equal, is pure white. (6) However, not all pure white surfaces have equal reflection power. There is density and character of the surface to consider.

(7) Loosely woven, untreated white cloth, for example, while it may be pure white, is nevertheless a very poor reflecting surface for the double reason that it permits a considerable percentage of the light to pass through, and because much light is absorbed by the fabric itself, into which it enters but does not pass through.

White cloth made of fine, hard-twist, closely woven thread is a good reflecting surface, (8) provided its back is properly treated with a pure white coating such as kalsomine, or white lead and white zinc (50-50 mixture) paint.

(9) White lead paint properly mixed and properly applied reflects a high percentage of incident light. White zinc is still better, but there are objections to its being used alone. A proper mixture of the two, half and half, with its slight yellow content killed with blue, is excellent. It provides a widely diffusing and efficient reflecting surface.

(10) Kalsomine also reflects well and has high powers of diffusion. Both paint and kalsomine are relatively low in cost, hence such surfaces may be easily and cheaply renewed when soiled or discolored by age.

(11) Metallic screen surfaces (aluminum paints) reflect well, but usually only through narrow angles, concentrating a large percentage of the light at the center of the auditorium. They have more or less "fadeaway" characteristics at side angles. Moreover, they are subject to chemical changes which reduce reflection power and in time change the tone of the reflected light.

(12) Glass bead screens have high frontal reflection powers and very low powers of diffusion. They may be cleaned better than other surfaces, but (13) their original reflection power cannot be restored, because the white pigment in which the beads are embedded is a part of the screen's reflecting surface and discolors with time.

(14) Glass bead screens are not suited for wide auditoriums or for theatres with balconies or steep projection angles. Bead screens are better suited for use in

long, narrow auditoriums where the projection angle is moderate and the balcony, if any, is low. Under such conditions they are highly efficient.

Reflection Power and Age of Screen

There are many different types of screen surface, some of which have excellent and some comparatively poor powers of reflection and diffusion. (15) The reflection powers of most screens are good when new, but some of them deteriorate quite rapidly. It is impossible to restore any screen to its original value through cleaning. Moreover, reflection power is lessened with each cleaning. Taking these facts into consideration, it is evident that both projectionists and exhibitors should study screen surface characteristics very carefully, basing such study upon (16) (a) reflection power when new and (b) rapidity with which various surfaces will discolor, or absorb and accumulate dirt, (c) probable percentage of original reflection power that may be restored by cleaning, (d) cost of refinishing the surface and (e) angles at which light will be reflected. It is important to select a screen surface that will most efficiently serve the seating space of the auditorium.

(17) The percentage of incident light reflected is a highly variable item. What percentage of light a screen surface will reflect when new and what it will reflect after six months' use are widely divergent facts. (18) Reflection power varies with the character of the surface. Exposure to air has a decided effect and so has the location of the theatre because in some sections the air is laden with impurities which settle on the screen surface.

It is therefore impossible to gauge exactly the loss of reflection power over a period of time. For example, in Buena Vista, Colorado, deterioration would be relatively slow because the mountain air is very pure and clean. In industrial centers, on the other hand, the air is filled with carbon dust and other impurities and screens lose reflection power quite rapidly.

Testing Reflection Power

(19) At the time of purchasing the screen insist upon an extra sample of not less than six inches wide by six feet long. A piece 18 inches square will serve equally well. Wrap this sample in at least two thicknesses of soft black cloth. Lay it away on the shelf of some dark closet where it will remain dry. Cared for thus, it will undergo little or no change for a long time unless its surface contains chemicals that discolor without exposure to light. To test the screen surface, suspend the sample, by means of small wire hooks as nearly as practicable in the center of the screen. Project a reel of pictures and observe the effect. A sheet of white, rough-finish cardboard will serve in place of the screen sample if that is not available. White blotting paper may also be used. Paper is not always satisfactory because its properties are not identical with the screen, but it will give a fairly good idea of the condition of the surface. The white paper test is valueless against a tinted screen surface.

It is better to make the test with a reel of pictures rather than with the light alone because actual working conditions yield a better comparison.

(20) No object or substance known to man reflects all the light striking its entire surface. There is always some loss. It cannot be truthfully said that the reflection power of any screen surface is in excess of 100 percent. It is always less than 100 percent.

However, some surfaces show more than 100 percent reflection power through a comparatively narrow angle, which only means that the other angles have been robbed of a portion of their light. (21) The situation is shown in the accompanying tabulation. Surface G, for example, shows 163 percent at 0 degrees angle, but at a 50 degree angle it sinks to 31 percent. The angles from 20 degrees down have been robbed of light to make the space within 20 degrees very brilliant. While the amount of total light reflected by a screen is important, it is not so important as the directions in which it is reflected.

(22) Despite statements made by screen salesmen,

photometric measurements of reflected light can be made. For the convenience of Bluebook readers the engineering department of the Eastman Kodak Company made a series of test measurements of the reflection and diffusion powers of certain well known surfaces which are tabulated below.

(23) In the accompanying tabulation each surface is given a designating letter, as follows: A—Magnesium, a chalk-like substance the reflection power of which was taken as a standard because of its high reflection value and uniform distribution powers. Its 0 degree angle of reflection power was arbitrarily assumed to be 100 for purposes of comparison with other surfaces. B—Fine grade cotton sheeting. C—Two coats of white paint on cardboard. D—Smooth calendered cardboard. E—Kalsomine on plastered wall. F—Wallboard painted two coats of aluminum paint.

TABLE NO. 6.

(Angles of light measuring instrument to screen surface when measurements were made.)

Surface	0 deg.	5 deg.	10 deg.	20 deg.	30 deg.	40 deg.	50 deg.	Average
A	100	100	99	98	98	98	97	99
B	61	61	60	59	58	57	56	59
C	80	79	78	77	76	74	70	76
D	113	109	106	94	83	80	79	95
E	82	82	82	81	81	81	81	81.5
F	132	125	115	88	66	50	37	73
G	163	150	134	93	61	43	31	96

The column of averages was arrived at by adding the reflections at all measured angles together and dividing by seven, the number of angles, which is only approximately correct but serves our purpose.

The variations are entirely due to differences in reflection characteristics of the various surfaces and difference in direction in which the light is reflected.

(24) Evidently surface A gives a good and very even screen brilliancy to people seated in all parts of a wide theatre auditorium, since the light is evenly reflected in all directions. There is no visible fadeaway. This sur-

face, however, is not available for theatre screens. B provides excellent power of light diffusion, but is relatively low in reflecting power. Surfaces D, F and G concentrate a large proportion of the total light at the

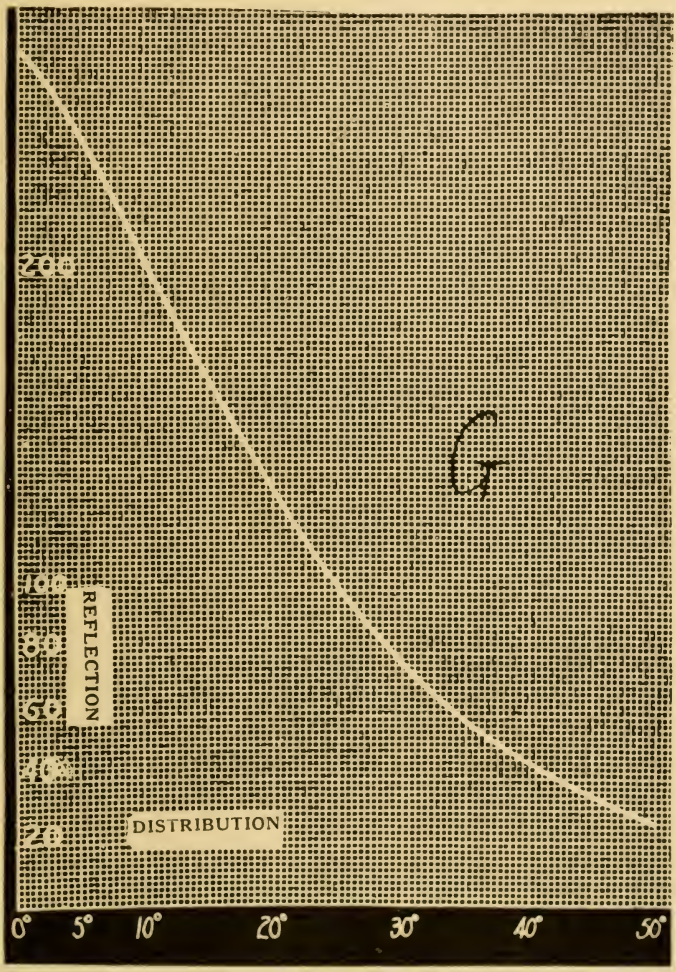


FIGURE 48

center of the auditorium. The picture would be very bright from straight in front of the screen, but quite dim at wide viewing angles. The total reflection power is high, but the distribution is very poor. They are obviously suited only for use in long, narrow auditoriums. Of the surfaces measured, C and E best serve wide theatres. Surface B is still better for light distribution but quite low in reflecting power.

Fig. 48 sets forth ratios of distribution of reflection power. Observe that vertically at the left are figures from 0 to 100 which represent reflection power of the surface. The extreme left edge is the line representing the reflection power of the surface when viewed from straight in front of the center of the surface—in line with the axis of projection. There the reflection power reaches to 370, one hundred representing its brightness where the light is evenly distributed. This added brilliancy is taken from the margins, which drop, you will observe, very low.

At the bottom are figures representing angles of view, or "viewing angles." The slightly curving white line represents the reflection power of the surface at every possible viewing angle up to 50 degrees. If you follow the vertical line immediately over 20 until it meets the white line, it does so at the horizontal line extending to the left of 100. This means that if the screen is viewed at an angle of 20 degrees it will only be as bright, compared with brightness when viewed from straight in front, as 100 is to about 370, while at a 50 degree viewing angle the illumination will drop until the brightness, as compared with a straight front viewing angle, will be only in the ratio of 30 to 370. This indicates the condition known as "fadeaway."

Fig. 48 and table No. 6 shows the necessity of careful investigation of reflecting and distributing powers of surfaces before installing a screen. Projectionists and theatre managers should require the manufacturer to supply such measurements and to check through with an expert testing organization.

(25) A study of the foregoing tabulation makes it evident that, important as reflection power is, the distribution of light is of even greater concern.

Light Tone

(26) Color, shade or tone of reflected light may be influenced to some extent by the character of the screen surface but without appreciably decreasing its power of reflection. Some theatres, employing the same light source, vary among themselves in the character of their screen illumination. Some have a sharp, harsh light; in others it is mild and pleasing. This may be due to factors other than the screen or it may be due to differences in the screen surfaces, though not necessarily to differences in surface tinting.

(27) Theatres using a mazda projection light source should install the most brilliant screen surface purchasable, paying due attention to the diffusion of light necessary to their auditoriums. Light source in such theatres would be limited in power and of a pale amber tint, as compared with an arc light. The problem, thereforce, is not to reduce harshness, but to procure a screen surface that will reflect the highest possible light reflection characteristics.

(28) On the other hand, theatres using high power, high intensity arc lamps, which provide the maximum amount of projection light, but of a more or less harsh tone, should have a screen surface of less brilliant white in order to reduce the harshness. This is another problem that deserves consideration by the exhibitor and projectionist.

Type of Surface—Side Angle Distortion

(29) As previously indicated, some reflecting surfaces will distribute or diffuse light evenly all over a wide auditorium while others will not, concentrating a large percentage within a relatively narrow angle. The first are diffusing, the second specular surfaces, and between these extremes are many different grades.

(30) Which surface will give uniformly best results in any specific auditorium will depend upon the width of the seating space near the forward end, height of balcony above main floor, and the nearness of front seats to the screen.

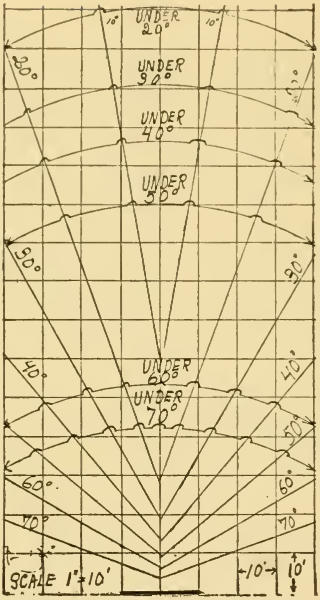


Fig. 49.—A straight edge laid on any of the lines will touch the side of the screen opposite. Anyone seated within the angle formed by these lines has a proper viewing position in relation to the screen.

(31) To know what kind of screen surface is best for your theatre you must know all the viewing angles. This may be ascertained by following Fig. 49, which is laid out in squares. Measure the inside dimensions of your auditorium. Each one of the vertical lines represents a ten-foot width. Each horizontal line represents ten feet of depth. If your auditorium measures 40 feet wide by 70 feet deep, you have only to count back from the screen to the seventh horizontal line in Fig. 49. Then count to the second vertical line on each side of the center line and you have your theatre floor plan laid out in the diagram.

Suppose your seating takes in the full width of the theatre —no side aisles—and that it comes within 15 feet of the screen and within 8 feet of the rear wall. That calls for a screen of high diffusing power, since a considerable number of seats will be beyond the 40 degree angle, many outside the 50 degree angle and a few even outside the 60 degree angle. It's a bad condition for two reasons: first, the best available screen surface cannot distribute light over so wide an angle without perceptible fadeaway, and secondly, it creates heavy visual distortion from the front side seats.

(32) Those seated at a heavy horizontal angle to the screen surface see all objects thereon as abnormally tall and thin. When an object we always see in certain proportions of width and height is suddenly reduced in width, it then appears to be taller than it really is.

Examining Fig. 50 we see an object of a certain width on the screen represented by A-B. An observer seated at C will see this object in its normal width, but an observer at D will not. He will instead see it as of B-G width. This effect is present in varying degree from any viewing angle, but is only objectionably noticeable when the viewing angle becomes sharp.

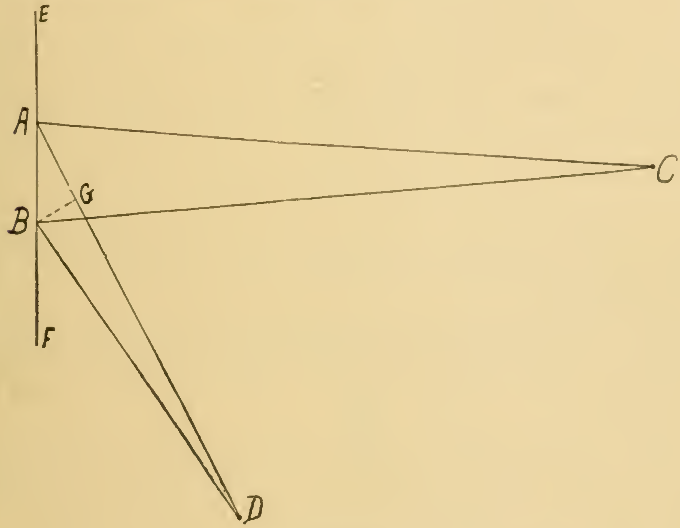


FIGURE 50

(33) No screen surface can remedy this condition. Reducing the viewing angle is the only remedy. When there are viewing angles such as shown in Fig. 50 exhibitors should install a screen of high diffusion power. As a matter of fact such angles should not exist in any motion picture theatre.

(34) According to Table No. 6 on page 150, the only screen for the theatre layout previously mentioned would be E. True, B is a trifle better in the matter of light distribution, but it is weak in reflection power. We need a surface approximating E in diffusion power, with the highest reflection power possible.

SCREEN MOUNTING

(35) The best screen mount is a strong frame with metal hooks, metal eyelets, and a rope lacing. It keeps

the screen stretched tight and flat and permits it to be taken out conveniently for restretching.

Cleaning Screens

(36) Do not accept any statement from a salesman or manufacturer that a screen surface can be cleaned to regain its original reflection powers. It cannot be done with any screen surface. Some surfaces when cleaned for the first time do regain a large percentage of their original values, but each time the cleaning process is repeated those values diminish. This is true even with glass bead screens. The beads themselves may be cleaned perfectly but there is the material in which the beads are embedded which is also a part of the reflecting surface and which loses reflecting power with each successive cleaning.

(37) Except glass, any substance now used for screen surfaces undergoes a chemical change with the passage of time. The change may be slow but it is steadily progressive.

(38) Some patent screen surfaces can be refinished successfully—but only by the manufacturer who makes them, and it is usually as costly as a new screen. In any case the theatre owner should make sure about such claims by the manufacturer.

Perforations

(39) From twenty to forty holes are punched in every square inch of screen surface. Thirty holes per square inch (144 × 30) totals 4,320 holes per square foot, or 1,049,760 holes in an 18 × 13.5 foot screen surface.

(40) Screen surface area cut down by perforation runs between 9 and 10 percent. To compensate for the loss of so much reflecting area, at least 9 percent more electrical energy must be used to secure screen illumination equal to that provided by a solid surface of equal reflection power. There is no compensation, however, for the loss in picture details, which is estimated to be about 10 percent.

(41) Perforated screens were introduced to permit the passage of sound from loud speakers behind, but competent sound engineers state that the loud speakers may be located either at the top, bottom or sides of the screen without impairing sound quality or direction. We will qualify such statements by saying that a solid screen can replace the perforated screen with equal or greater efficiency in all theatres except those wherein a considerable percentage of the audience views a picture from an angle greater than thirty-five degrees in relation to the screen.

How to Obtain Viewing Angles

(42) It is an easy matter to calculate the viewing angle from any portion of a theatre to the center of the screen. No special equipment is required. Make a mark in the horizontal center of bottom of the screen,

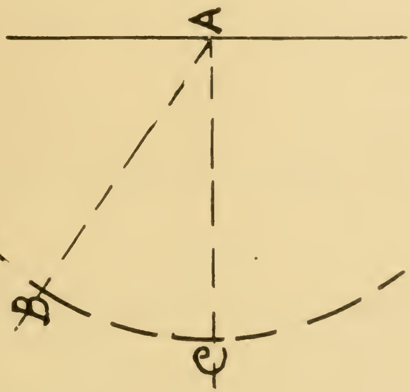


Figure 51

calling it point A. From this mark measure the distance, in inches, to the center of the back of the seat for which calculations are being made. Call this point B. From point A stretch a line back at exactly right angles to the screen surface, a distance a little more than equal to the distance from point A to point B. Use a good carpenter's steel square to get the angle. Anchor this line to a board laid across the center aisle on the chair backs. From point A measure along this line a distance equal to the distance from point A to point B, and tie a string to the line. Next from point B measure the distance to the desired point, in degrees, from the center line. Call this point C. The plan is shown in Fig. 51.

We now have points A, B and C established. Next multiply two times the distance point, A to B, in inches, by 3.1416, and divide by 360. The result will be the length, in inches, of one degree of the circumference of a circle, the radius of which is the distance from point A to point B. If we now measure the distance from B to C in inches, and divide by the length of the degree, we arrive at the number of degrees point C is from the center line of the theatre. This is termed the "viewing angle." The same calculation may be made from any point in the auditorium to any point on the screen.

Because we have measured in a straight line from B to C, our answer will not be precisely correct, but near enough for all practical purposes. If an exact calculation is desired, lay several short, wide boards on the chair backs along the arc of the circle found by swinging point C (mark on line) around from C to B. Trace the circle along the boards and measure the length of the arc exactly.

Perforated vs. Solid Screens

(43) Perforated screens are rated lower than solid screens for several reasons.

They require more frequent cleaning and refinishing than solid surfaces because the air circulating through the hundreds of thousands of tiny holes leaves a deposit of dust in the walls and around the rims. Discolorations caused by gases soon appear, inducing the reflecting power of the screen to diminish rapidly. It is more difficult to clean a perforated screen than a solid one. Without a suitable apparatus and experience it is equally hard to refinish a perforated screen without reducing the perforation diameters or filling them in completely, thus reducing and (or) setting up uneven sound distribution.

Distance of Screen to Front Seats

(44) Too little distance from the front row of seats to the screen sets up a wide viewing angle, which is bad. It also tends to decrease sharpness of the screen image when viewed from the front seats. In general it tends to destroy the illusion that speech comes from the lips of the players.

(45) The front row of seats should never be closer than 20 feet from a 16-foot picture. If the screen is larger add one foot three inches of additional distance for each foot of additional screen width.

Taking this as a basis, it is a simple matter to calculate the distance required for any picture width. The greater the distance from the front seats the more comfortably the people sitting there will enjoy the picture. It must not be carried to excess as it would accomplish no good purpose except to reduce seating space unnecessarily. There is no eye-strain involved for those of normal eyesight located one hundred feet from a well-illuminated 16-foot picture. This distance may be accepted as a safe guide.

Height Above Floor

(46) Height of screen above the floor depends largely upon local conditions. It is usually best to have the picture located as low as possible without concealing the view of its lower portion from any seats in the auditorium. The chief objection to height is that it detracts from complete naturalness. A good picture perfectly projected helps the audience forget that it is facing a make-believe world and creates an illusion of real people in real life. The position, size and illumination of the screen are factors that help to create this illusion.

Effects Governed by Dimensions

It is well known that if the front seats are too close to a large screen the image will lack sharpness. It will have a "fuzzy" appearance. This is the natural effect of the tremendous magnification of the film photograph when viewed too closely. It is very hard on the observers' eyes and detracts from the enjoyment of the picture.

Again, when placed too close to the screen the theatre patron must cover an excessively wide viewing angle, which is very hard on the eyes. He is also subjected to a foreshortening effect as illustrated in Fig. 50, if seated in one of the end seats.

(47) As screen image dimensions are increased the amount of light must also be increased to maintain the brilliancy of illumination.

(48) A study of percentage factors of illumination for various sized screens reveals a startling differential which must be counterbalanced by a proportional increase in light energy. The accompanying table tells the story at a glance. Let us take a screen size of 10 × 12 feet as a unit of measurement. We will assume that the illuminating factor of this screen under proper conditions is 100. If the same amount of light is projected on screens of increasing sizes the drop in illuminating values is as follows:

10	× 12 =	120	sq. ft.	100 percent
12	× 16 =	192	sq. ft.	39 "
12.75	× 17 =	216.75	sq. ft.	34 "
13.50	× 18 =	243	sq. ft.	29 "
14.25	× 19 =	270.25	sq. ft.	27 "
15	× 20 =	300	sq. ft.	25 "

(49) Moreover, increase in picture dimensions require a very rapid magnification of the film photograph.

(50) The linear magnification may be determined by dividing the width of screen image, in inches, by width of the projector aperture.

(51) The larger the screen the more quickly defects in the film will be sighted by the audience, if a brilliant illumination is maintained.

(52) There is no advantage gained from mere size or from brightness of illumination unless it is required by the conditions of the theatre. A very bright picture is unquestionably very hard on the eyes. Subdued illumination may be just as hard because of the straining after the darker details in the screen image. A properly illuminated 16-foot picture has better visibility than an

inadequately illuminated 20-foot picture, and the smaller picture will be more pleasing to those in the front seats.

(53) Most theatres would be best served by a screen 18 feet wide, although large theatres have gone in for larger screens on the theory that the size of the picture is related to the size of the auditorium. While this is true up to a certain point the real relation is between the screen and its immediate surrounding area, particularly if it is an unbroken wall. If this surrounding area is broken up and decorated in a series of small areas the small screen will be proportional from all parts of the theatre. Better than a large screen, the small one offers a compact film image which, when properly illuminated, is pleasing and effective from all parts of the theatre. Small pictures are unsatisfying when they do not conform to surroundings.

There is no undue eyestrain in viewing a well illuminated sixteen foot picture at 100 feet. As a matter of fact, a sixteen foot picture can be viewed comfortably at an even greater distance, with no eye fatigue, provided the screen is properly illuminated. (54) No matter how small the theatre the width of the screen should not be less than ten feet. As already indicated only a very large theatre of 4,000 to 6,000 seats requires a screen image larger than eighteen feet.

Tinting

(55) Tinted screens were first used to neutralize harsh light rays to give the screen image a softer effect. But since films are sometimes made on tinted stock and also because we are getting an increasing number of color films, tinted screens today are of questionable value. Projecting a color picture on a tinted screen may result in a bizarre effect. It is safest to undertake no experiments with tinted screen surfaces.

Location and Surroundings of Screen

(56) If the screen is located on the stage it should be as far back as conditions will permit. A rear location

will help reduce the projection angle and make vision from the front seats more comfortable.

(57) If there is a balcony the floor in front of the screen should be covered with a black cloth or painted a non-gloss black.

(58) Provided the viewing angle from the front seats is not too great the screen may be located in "one" with good effect, but whatever the location it is extremely important that its surroundings be inconspicuous. No object must distract the eye while the picture is on the screen.

(59) The border should be plain non-gloss black next to the picture. This may be shaded gradually over a distance of not less than three feet into some lighter tone (silver gray) in harmony with the surroundings.

The theory has been advanced that the sharp contrast between a black border and the white light tends to raise the apparent screen illumination near the edges of the screen above its center.

This might be true were the screen evenly illuminated, (60) but as a matter of fact screens are not evenly illuminated under the best condition. Illumination is always highest at the screen center. It falls off sharply to the outer margins. The difference is often as much as fifteen c. p. at center and as low as five at the margins. The effect of sharp border contrast therefore would be to level the illumination for all parts of the screen.

A dead black border next to the screen allows the picture edges to overlap upon it an inch or two. This tends to make less visible any movement of the screen image as a unit.

Paint, Kalsomine, Etc.

Perforated screens cannot be improvised. The exhibitor must choose the one that meets the requirements of his theatre from those offered by manufacturers. But if he uses a solid surface screen, he may make his own, (61) since he, himself, can apply a coating that will have excellent powers of reflection and diffusion. (62) Such a screen, in the end, may be more efficient than any other because it can be recoated frequently, at low cost, presenting a fresh surface at all times.

Best Frame

The day of stretching screens and nailing them to a wooden frame is past. (63) Most commonly used today for mounting and stretching is a frame of wood or other material equipped with strong metallic hooks on all four sides which correspond with metal eyelets all around the screen edges. These eyelets should be no more than six inches apart. With the aid of a heavy cord a screen may be mounted quickly, stretched evenly and tightly and restretched as often as necessary.

(64) Properly prepared paint and kalsomine have excellent powers of reflection and diffusion.

Paint Surface

(65) If the screen body is of raw cloth it should be mounted on its frame and painted with one or two coats of glue sizing made by dissolving from one to two pounds of glue, according to its quality in a pail of hot water. It will be best to place the glue in hot water and let it set over night. In the morning heat and stir it until it is thoroughly dissolved. Then, with a brush, saturate the cloth thoroughly with it. If a second coat is to be applied, wait until the first has dried thoroughly.

If you are refinishing an old screen, sizing may not be necessary. If the glue fails to stick to the surface it may be necessary to size with shellac. Shellac may be purchased ready for use, but may need considerable thinning with wood alcohol. Brown shellac is just as good and much cheaper than the white.

After sizing the surface with glue, apply a fairly heavy coat of white lead, mixed with half boiled linseed oil and half turpentine, as a base coating. Let it dry thoroughly and then apply two coats of half white lead ground in oil and half white zinc ground in oil, mixed with one-fourth boiled linseed oil and three-fourths turpentine, into which sufficient ultramarine or cobalt blue has been mixed to give the paint a decided blue tint while in the pot. It's the laundryman's principle of putting blue in the rinsing water to whiten the clothes.

Mix the paint rather thin and let each coat dry thoroughly before applying the next. It is a "flat," quick-drying paint, and must be applied fast to avoid brush marks and "laps." When finished the surface will reflect well and have excellent power of diffusion. Apply a new coat as soon as the new surface has dulled. Where the air is laden with dust, gases and carbon dust, a new coating should be applied probably every three months. Where the air is pure the screen will remain fresh and clean for longer intervals.

Kalsomine

(66) Another surface which gives excellent results, though it lacks the high reflection power of paint, is a white kalsomine selling under the trade name of "Alabastine." All patent kalsomines are good, but alabastine has properties particularly favorable to screen surfaces.

Size the screen as previously indicated. Mix the kalsomine according to directions contained on the package. Apply with a good kalsomine brush, working fast to avoid laps. Don't attempt to use a cheap, poor brush. Unless some theatre employee understands how to apply kalsomine it will be best to have a local painter do the job.

Kalsomine surfacing costs very little and can be washed off easily before applying a new coating. Many exhibitors have used it with good results.

Recoating Perforated Screens

(67) When it becomes necessary to recoat a perforated screen, it should be sent to the manufacturer or be done at the theatre by his own men. The exhibitor can attempt it himself but the results cannot be guaranteed. (68) The difficult thing is to avoid partially filling in the perforations.

Either paint or kalsomine should be used—these being the best for coating when the job is undertaken by the theatre. (69) If paint is to be used, try a small section at one of the bottom corners. If it adheres, apply it as suggested below. (70) If it doesn't adhere, wash it off carefully with a soft rag dipped in turpentine. Try shellac the same way. If it sticks, apply a thin veneer all over the screen surface, let it dry and then apply a thin coat of paint.

(71) When coating a perforated surface, the perforations can be kept partially free with the aid of a suction hose attached to a vacuum cleaner operating on the other side of the screen, working in time with the movement of the brush. The regular dust bag of the vacuum should be replaced by gunny sacking. If there is no room for the operation back of the screen, the screen should be dismounted and stretched on a temporary frame. (72) A spray gun for the resurfacing job is much better—it will not clog up the perforations as much as a brush does. In any case, the size of the holes must not be decreased or it will have a bad effect on the sound.

If kalsomine is used instead of paint follow the same general method but apply thin coats only. Never put heavy coating on perforated surfaces.

Screen Sizes

(73) The Projection Screens Committee of the Society of Motion Picture Engineers suggests the following screen sizes as best for present-day projector aperture dimensions. The height and width are as 3 and 4. For an 18 degree projection angle such a screen will require a minimum of masking.

TABLE NO. 7. SCREEN SIZES

8′ × 6′	14′ × 10′ 6″	20′ × 15′
9′ × 6′ 9″	15′ 11′ 3″	21′ × 15′ 9″
10′ × 7′ 6″	16′ × 12′	22′ × 16′ 6″
11′ × 8′ 3″	17′ × 12′ 9″	23′ × 17′ 3″
12′ × 9′	18′ × 13′ 6″	24′ × 18′
13′ × 9′ 9″	19′ × 14′ 3″	25′ × 18′ 8″

(74) Authorities believe that the auditorium illumi-

nation should be approximately 0.18 of a foot candle, approximating the illumination necessary to read theatre programs printed in 8-point type. It is sufficient to enable patrons to locate seats. It does not greatly affect contrasts of light and shade on the screen.

(75) The picture is a matter of contrasting shades. Rays from an auditorium light falling upon the screen illuminate all parts. These rays do not alter the white portions, but they light up the deeper tones and thus reduce contrasts.

(76) Permit no direct rays of light to reach the screen from any source other than the projection lens. Permit no "glare spot" of light within view of the audience.

(77) A "glare spot" is a concentrated spot of white light of considerably higher brightness than surrounding objects and has a bad effect both upon the eyes and upon the screen image.

(78) Viewing comfort is ability to see all details of a picture without strain. It is attained by a combination of brightness and area. Viewing may be made more comfortable for the eyes either by increase in picture area or by increase in screen brightness. Viewing comfort is ability to see all details of a picture without strain.

THE FILM

1. What two different kinds of 35 mm. film are there?
2. What is the width of film in inches?
3. What are its other dimensions?
4. Describe, in general, the process of manufacture.
5. What are the photographs impressed thereon?
6. What are the dimensions of a film "frame"?
7. Exactly what length of film is occupied by each frame?
8. What are the present approved dimensions of the motion picture projector aperture?
9. Upon which side of the projector aperture is the sound band located?
10. Is the picture over the projector upside down?
11. How wide is the sound track?
12. What two different methods of sound impression are used?
13. Which is the R.C.A. method and which the Western Electric?
14. Is the sound impressed on the film simultaneous with the picture?
15. Is the sound impression on the film always in perfect synchronization with motion?
16. By whom is the film perforating usually done?
17. How many perforations are there to each frame?
18. How many frames are there to each foot of film?
19. How many perforations are there to each foot of film?
20. What characteristics of film concern the projectionist most?
21. What are the obligations of a film exchange?
22. Does the exchange hold itself responsible for sending theatres clean and safe film?
23. Are projectionists responsible for accidents resulting from bad film sent by the exchange?
24. Is it the duty of the projectionist to inspect films before using them?
25. Is it the duty of the projectionist to make repairs upon films?

Cause of Damage to Films, page 175

26. Name the principal causes of damage to film.
27. How may such damage be avoided by the exchange in co-operation with the projectionist?
28. For what reasons do mismatched sprocket holes inflict damage upon films?

Splicing Film, page 179

29. Is a poorly made splice likely to cause damage to film?
30. Upon what does a perfect film splice depend?
31. Name the things necessary to make a good splice.
32. What will happen to film cement if it is exposed to the air?
33. How should cement be applied?
34. What is vitally necessary in making a splice of maximum strenth?
35. Is heavy, evenly applied pressure essential in making a splice and for how long must pressure be exerted?
36. What will be the result if too little or an uneven pressure is applied?
37. Can a proper splice be made without the aid of a splicer?
38. Does dry scraping of the stub end in making splices produce reliable results?

Storing Films in Theatre Projection Rooms, page 183

39. Should other things beside fire hazard be considered in storing film?
40. To keep film pliable must it be stored in a humid atmosphere?
41. What operates to drive moisture out of film quickly?
42. How can the moisture content be restored?
43. Are water tanks filled by hand efficient?
44. Describe the nature of an efficient film storage cabinet.

Handling Film, page 185

45. What is the first duty of the projectionist as soon as his film arrives?

46. Should the projectionist notify the theatre manager and the exchange manager of the condition of newly-arrived film?
47. If the exchange fails to heed complaints, what other agencies should be notified?
48. Where should all film, not in the projector, be kept?

How to Rewind Film Correctly, page 186

49. What is the minimum time required to rewind 1,000 feet of film properly?
50. Is low speed rewinding of benefit to the projectionist?

Rewinder, page 186

51. Where should the rewinder be located?
52. Why is it undesirable to locate the rewinder away from the projection room?

Rewinder Details, page 187

53. How may a piece of ordinary glass be ground?
54. Must the rewinder elements be in perfect alignment?
55. Do rewinder elements out of line damage the film?
56. Is a reminder tail reel brake necessary?
57. Is a switch to automatically stop the rewinder necessary?
58. Describe an ideal rewinder.
59. What should be installed immediately over the rewinder?
60. How may pulley sizes to reduce rewinding speed be calculated?

Film Shipment Reels, page 191

61. Name the points of importance with regard to shipping.

Projection Room Reels, page 191

62. Should the use of a set of projection room reels be made mandatory?

Footage Capacity of Shipment Reels, page 191

63. What is the most desirable footage capacity for reels?
64. What are the objections the exchanges make to the 2,000-foot reel?
65. Why does the projectionist object to the 1,000-foot reel?

How to Estimate Footage of a Roll of Film, page 193

66. Why is it impossible to calculate the footage of a film roll accurately?
67. How can a fairly accurate estimate of footage be calculated?
68. How may the footage be calculated with the aid of the projector mechanism?

Removal of Emulsion, page 194

69. How may emulsion be removed from film?
70. What is the best method for cleaning film?
71. How is film cleaned with gasoline or benzine?

Rain, page 194

72. What is rain?

Keep the Films Clean, page 195

73. Is it possible to prevent oil from reaching the film?

Standard Release Print, page 195

74. Of what does the change-over cue consist?
75. Is the dowser operated the instant the change-over cue appears on the screen?
76. How may projectionists make visibility of cue mark easy and certain?
77. Of what does the motor-start cue consist?

78. Why is the motor-start distance to the change-over twelve feet and six frames?
79. Describe process of ascertaining the exact motor pick-up speed.
80. How should the correct start-frame number for each projector be reached?
81. Will motor pick-up speed always be the same?
82. Must motor pick-up speed be ascertained for each projector?
83. How is the standard release print started?
84. Can the standard release prints be used to check for synchronism?
85. How can exact synchronism be assured?
86. How is the standard release print threaded for synchronism with disc record?
87. Do cut-outs work injury to standard release print performance?

CHAPTER VII.

THE FILM

(1) The 35 millimeter-wide motion picture film is usually nitro-cellulose (inflammable), though cellulose acetate (slow-burning) is available. The two are exactly the same, except for their ingredients. (2) The 35 mm. film is 1.376 to 1.378 (practically 1⅜ inch) wide. (3) Its various dimensions, as approved by the Society of Motion Picture Engineers, may be examined in Fig. 54.

(4) Celluloid, from which films are made, is manufactured in wide sheets approximately 2,000 feet in length. These sheets are coated with photographic emulsion, some negative and others positive, according to their purpose. They are then split into ribbons 35 mm. wide and perforated. The combined thickness of the film stock and the photographic emulsion is from five and one-half to six thousandths of an inch. The photographic emulsion is about 0.001 of an inch thick.

(5) The camera impresses a series of snap-shot photographs upon a negative film at the rate of 24 per second. (6) The over-all dimensions of these "snap-shots" are 0.631 inch by 0.838 inch. The chief difference between the negative impression and the photograph on the positive print is that everything is in reverse, the clear whites in the negative will be opaque blacks in the positive, and opaque blacks in the negative will be clear white in the positive print, with graduated shading of tone. (7) In both negative and positive, each photograph and its surrounding dividing line (known as the "frame line") occupies precisely 0.75 (¾) of an inch, or 16 "frames" to each foot of film.

(8) Today the dimensions of the motion picture projector aperture, as approved by the Society of Motion Picture Engineers, is .600 by .825 of an inch. Note that

the motion picture projector aperture is smaller than the photographs on the film.

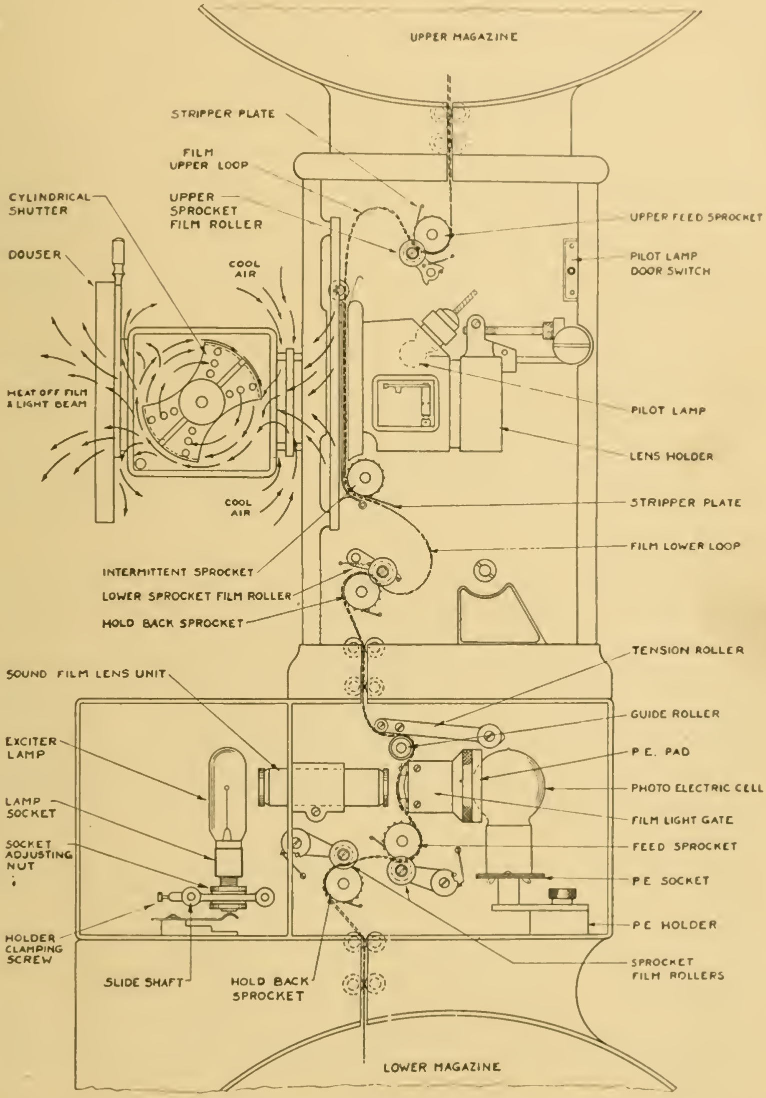


FIG. 53.—Path of film through Motiograph DeLuxe projector and sound head.

In Fig. 54 we see the film, emulsion side toward us, with the image, were there one, upside down. In other words, if we look at the film from the emulsion side, with the picture wrong side up, the sound band will be at the right, as in Fig. 54, in which it is labeled "scanned area." (9) It will be on the right side when the film is in the projector, (10) the film always being threaded into the mechanism with the image upside down. (11) The sound track is 0.084 inch wide, with an allowable tolerance of error of 0.002 inch. (12) The sound is photographically impressed upon this sound band, either in the form known as "variable area" or "variable density," (13) the first being the RCA method, the second the Western Electric method. These two methods are explained on page 426.

(14) The sound impression may be made on a film simultaneously with the photographing of the scenes—but on a separate negative or, as the news reels do, simultaneously on the same negative—or they may be made at separate intervals. In any case, the sound and the image are in synchronism when they are combined in the positive print.

(15) When sound and scenes are made at different intervals of time the lip movement may not be in exact synchronism with the sound, though close enough so that the audiences detect no imperfection. Where sound and picture is impressed upon separate films, as is usually done, there are certain guiding synchronizing marks impressed on each so that when the sound and picture are later combined in the positive print the effect is perfect.

(16) The producer may purchase unperforated stock and perform the perforating operations in his laboratories though most producers use perforated stock, both negative and positive. (17) There are eight perforations, or sprocket holes, to each frame of pictures, four on each side. (18) There are sixteen frames and therefore (19) 128 perforations, 64 to a side, to each foot of film.

(20) It is important to examine the rights of the projectionist concerning the film while it is under his charge and what he has the right to expect from the film ex-

change in clean prints in a good state of repair that may be safely projected.

What an Exchange Contracts to Do

(21) When and exchange contracts to supply film service to a theatre it agrees, unless for some reason it is otherwise stipulated, to provide (a) prints in first-class condition, safe in every way for the grueling grind through the projector for hours each day. Automatically the exchange becomes morally and legally responsible for fire or other accident that results from faulty prints, though it must be noted that the projectionist is not relieved from the duty of inspecting the prints before starting operations for the day. (b) The exchange also undertakes to provide clean film. (22) It becomes a reasonable assumption that the exchange holds itself responsible for providing the theatres with clean and safe working prints.

(23) It is equally evident that the projectionist cannot legally be held responsible for accidents resulting from imperfect prints nor for a poor screen image and bad sound because the prints are oily and dirty.*

(24) Although the projectionist is never relieved from his moral duty to provide the utmost safety for the people in his theatre, it is nevertheless no part of his duties to make repairs on film received imperfectly from the exchange. (25) It is, however, decidedly the projectionist's duty to repair all damages done to the film while it is in his possession and to return the prints in as good a condition as received.

Cause of Damage To Films

(26) Films may be damaged in many ways. The principal causes are:

Shipment to or from theatres without proper packing and/or rough handling while in transit.

Damage to sprocket holes because of worn sprocket

*These statements were examined and fully discussed by the Projection Practice Committee of The Society of Motion Picture Engineers at a regular meeting held March 7, 1934, and were unanimously approved.

teeth and/or too much tension at the projector aperture or take-up. Excessive tension works a great deal of

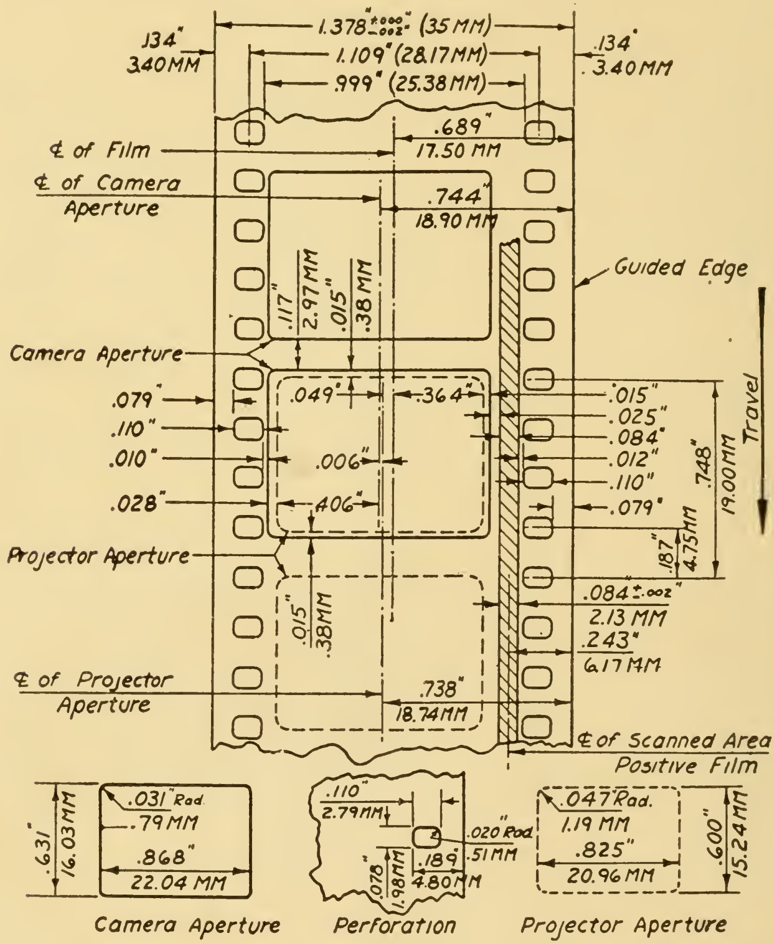


FIG. 54.—35 MM. Sound Film showing camera aperture, projector aperture and scanned area. These dimensions and locations are shown relative to unshrunk raw stock. Positive; emulsion side up. Negative; emulsion side down. In the camera the emulsion side of the film faces the objective. Viewed from the objective the sound track is to the left. In the projector the emulsion side of the film faces the light source. Viewed from the light source the sound track is to the right.

damage, especially if the sprocket teeth are hooked or undercut.

Imprint of the sprocket teeth on the film brought about when the film runs off the sprocket, which may be caused by badly adjusted sprocket idlers, poorly made splices, loose splices and by other means.

Scratches in the emulsion due to rewinding without a proper tail reel brake, which requires that the film roll be pulled down by holding one reel stationary while the other is being rotated; by bits of emulsion or film cement that stick to the projector parts, the emulsion side of the film rubbing against them in its passage through the projector.

Dry and therefore brittle film which is easily susceptible to damage.

Excessive speed of rewinding, particularly if the rewinder elements are out of line with each other.

Loose splices caused by improper scraping of the emulsion from the front and careless removal of oil or dirt from the back of the splice or by poor or damaged film cement. Too much or too little cement is also bad. Insufficient or unevenly applied pressure upon the splice while it is "setting" is often the cause of trouble.

Punching, scratching or pasting on of change-over marks.

Punching of identifying marks on the film by the exchange which the projectionist must remove to avoid their appearance upon the screen.

(27) All the foregoing types of damages to film and, additionally, many others, may be avoided if the exchange and the projectionist conscientiously exercise care in their handling of prints.

Prints should be packed in shipping cases tightly so that they cannot move around when in transit.

Reels should not be overloaded with excessive footage.

The outer layer of film should be protected by paper bands pulled tightly and well secured.

Proper inspection should be made at the exchange to repair loose splices; untrimmed or cracked sprocket holes and torn parts, particularly, tears or cracks at the divisions between sprocket holes.

Rewinder elements in the projection room should be in perfect alignment so that the film will not rub on either side of the reel.

Film should be rewound at the rate of six minutes for each 1000 feet of film—and no faster.

Avoid excessive tension by properly setting the tension at the projector aperture and at the take-up.

All sprocket idlers should be adjusted properly.

All sprocket idlers should rotate easily and smoothly so that they will not wear flat on one side.

Watch all sprocket teeth and replace them at once if they show signs of hooking or undercutting.

Allow no scraps of emulsion or bits of film cement to accumulate on any portion of the projector film track.

Maintain proper tension upon the reel in the upper magazine to avoid overrunning of the film and the consequent jerks to take up the slack.

When running soft, new film, watch out for collection of scraps of emulsion and film cement upon the tension shoes. These deposits generally come from too much tension at the aperture.

Make splices carefully following the procedure outlined on page 179.

See that the reel that is being rewound has enough tension to make the film fit snugly on the other reel, eliminating the constant "pulling down" process by hand which is the cause of much damage to film.

Keep the projection room perfectly clean. Dust in the air settles upon and scratches the emulsion side of the film.

And above all do not permit untrained assistants to make splices or other repairs to the film. A great deal of trouble is started that way.

(28) Mismatched sprocket holes resulting from careless splicing do much damage. They will "clamp" or stick on a sprocket tooth and pull the film around the sprocket. Often sprocket teeth will climb out of the sprocket hole and travel along the face of the film, making indentations that will show up on the screen or be heard in the auditorium, if the sound track has been defaced. Mismatched sprocket holes at a splice cause the screen image to jump every time they pass over the

intermittent and tend to give a side motion to the screen image as they pass the aperture.

Splicing Film

Bad splicing is the source of more trouble than almost

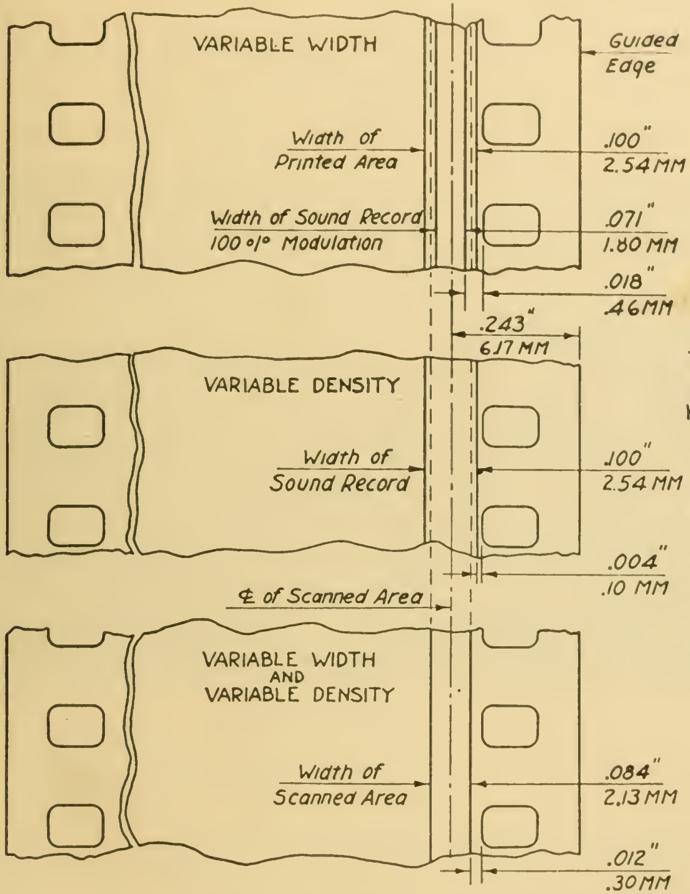


Fig. 55.—35 MM. Sound Film showing sound records and scanned area. These dimensions and locations are shown relative to unshrunk raw stock. Positive; emulsion side up. The dimensions as shown include the necessary allowance for film weave.

any other factor. The varieties of damage it causes film are almost too numerous to count. (29) For example, a splice that tears loose at one side only, lets the edge of the film catch on a sprocket idler, either ripping the film in two or splitting it down its length for several feet. It stops the show and creates a dangerous fire hazard. (30) Three factors are important in the making of a good splice: careful, intelligent work, good film cement and the proper tools.

The day of hand-made splices is past. The several film splicers on the market all give good results and one of them should be in every projection room.

(31) In making splices, film ends should be cut at the right place and cut square. The stub end must be exactly the right length; if it is too short it will be weak and if it is too long it will be stiff. Scrape the emulson from the

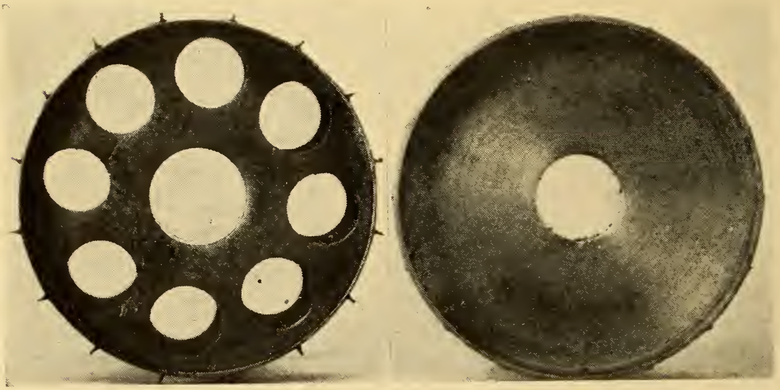


FIG. 56.—Examples of worn intermittent sprocket teeth.

stub end exactly to the center of the frame line and no further. The line at the end of the scraping must be straight and at right angles to the length of the film Scrape to the proper depth so as to remove all the emulsion and slightly roughen the celluloid beneath. If the emulsion is not all scraped away the splice will not hold. If the scraping is too deep it will weaken the film. If the film is dry and inclined to brittleness the splice will break after a short time. These are factors that have to be watched carefully in the process.

The rear or celluloid side of the film must also be scraped slightly to remove dirt and oil and to roughen the celluloid a little.

Above all use good cement.* If it is kept from contact with the air it will remain in good condition for a long time. (32) If cement is exposed to the air it will evaporate some of its content, absorb moisture quickly and make very weak, poor splicing material.

(33) Film cement is not rubbed on. It is applied with a small brush. Do not pass the brush across the film

FIG. 57.—Example of stiff, wide, splice going over sprocket. Observe how film is raised off face of sprocket; the image on the screen passes through a series of convulsive movements.

more than once. No satisfactory explanation has ever been forthcoming why more than one brush stroke of cement across the face of a film weakens the splice but long experience in projection rooms points to it.

(34) To make a strong splice the cement should be laid on with one stroke of the brush—an application that requires skill and judgment that comes from practice.

*Inflammable and slow-burning film cannot be spliced with the usual cement used for flammable stock. It requires a cement especially made for the purpose.

(35) Join the two ends and apply an even, heavy pressure for at least five or six seconds—while you count six slowly. (36) Lack of sufficient pressure, or pressure unevenly applied, will result in a weak or otherwise imperfect splice. Excessive pressure, no matter how much, will do no harm.

(37) It is impossible to make a really good splice with the unaided hands for the reason that the film, most probably, will not be cut square or have a correct stub

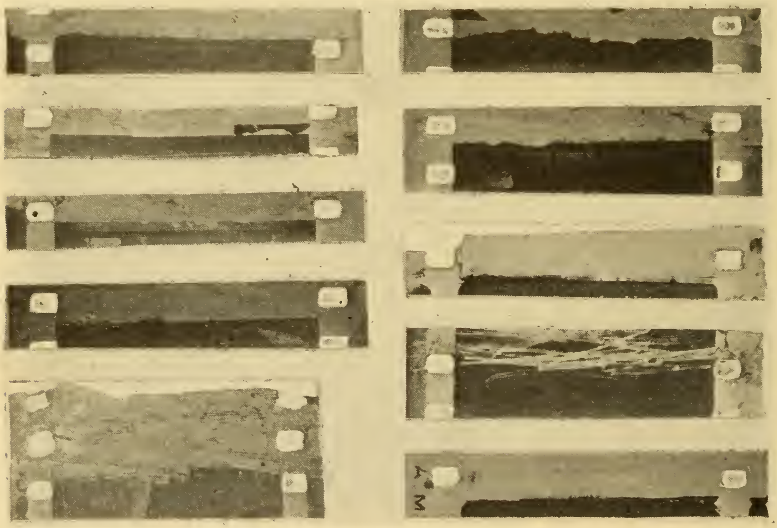


FIG. 58.—Samples of inefficient stub-end scraping. They are all parts of film splices made in projection rooms.

end length; also the pressure will certainly not be evenly applied. An efficient mechanical splicer cuts both ends perfectly square and cuts the stub end at precisely the correct length. It applies ample, evenly distributed pressure and automatically matches the sprocket holes perfectly.

(38) All forms of dry scraping of stub ends in making a film splice are unreliable, because the emulsion is only approximately 1/1000 of an inch thick, and it is obviously impossible for a projectionist to maintain an

adjustment that will remove 1/1000 of an inch of surface, and no more.

A dry metal scraper adjusted to remove just enough surface will wear away slightly after the first half dozen splices so that thereafter a thin coating of emulsion will always remain on the stub end. If it is adjusted to remove a bit more than is necessary, it will weaken the stock and the splice. It is, therefore, better to have a splicer that depends on wet scraping. If this is not available, remove the scraper from the splicing mechanism and perform the operation by hand. In that event provide the splicer with a properly located straight edge.

Wet scraping by hand gives little trouble if the brush and water are handily located and a safety razor blade, clamped in a holder, is used. A good blade holder may be secured in almost any Woolworth store.

The projectionist may construct a home-made splicer, but we advise against it because a home-made affair is not likely to do the job as perfectly as a well designed, well constructed factory-made mechanism.

Storing Film in Projection Rooms

(39) Proper storage of film in projection rooms has been considered heretofore almost wholly from the viewpoint of fire hazard—an error of thought that has cost exhibitors many thousands of dollars that might otherwise have been saved.

(40) New film is very tough and pliable. It may be sharply bent or creased without breaking, a condition that would last almost indefinitely were film always stored in humid atmosphere. But unfortunately it seldom has been in the past either in the exchange or in the projection room.

(41) In the course of projection the intense heat of the spot at the projector aperture raises the temperature of the film, driving out a portion of the moisture it contained. (42) Were the film rewound and immediately stored in an atmosphere of high humidity, at least a goodly portion of the expelled moisture would be recovered.

The storage of film in a humid atmosphere, to be fully effective, must be done in all theatres. Almost every projection room is now equipped with a film storage cabinet, but we believe that few of them have adequate provision to keep the air inside constantly moist. (43) To do so, each cabinet should always contain a

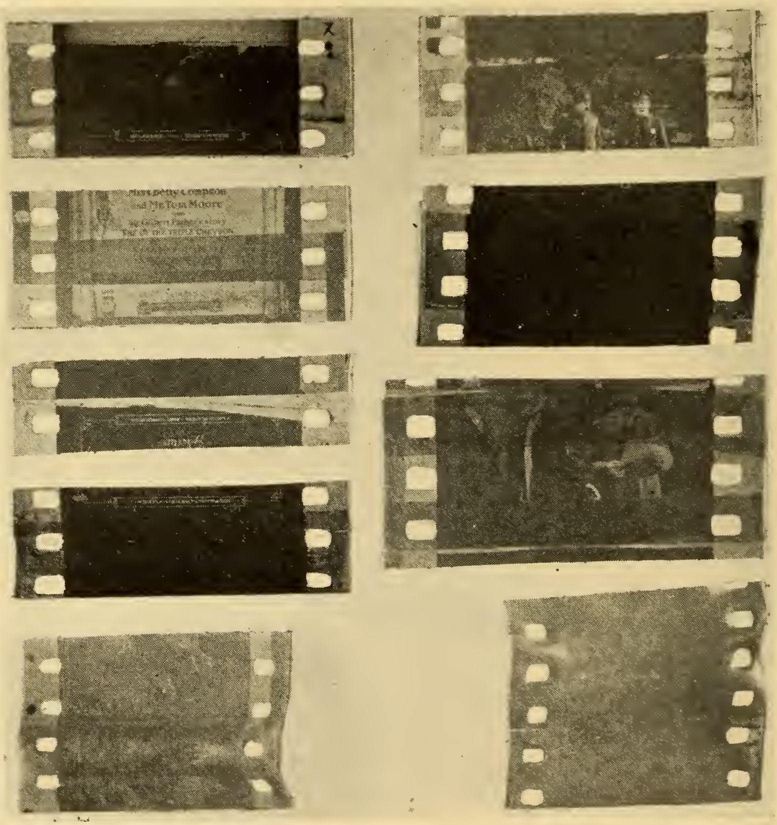


Fig. 59.—Examples of extremely bad film splices.

body of water. The water surface should be ample to insure sufficient evaporation and keep the air in humid condition. Water tanks that are filled by hand cannot be depended upon to serve the purpose adequately, as they are either neglected or entirely forgotten. (44) To insure proper conditions all film storage cabinets should be equipped with a water pan or tank capable of holding not less than thirty-six square inches of water surface for each reel it is designed to hold. The tank should be connected with the water supply and controlled by an automatic valve that will maintain the water level, feeding water automatically to the tank when the water surface drops down to a fixed, pre-determined point. Each tank should be supplied with an overflow, so that under no condition will the water ever reach the film.

Handling the Film

(45) The audience should be the first consideration of the projectionist. Its ultimate safety is the thought uppermost in his mind every minute of the working day. Consequently when film shipments arrive his duty is to make a careful check to discover any likely faults such as loose splices, ripped sprocket holes, etc.; if the film is dirty or streaked with oil it should be cleaned before being put into the projector so as to give patrons pleasing performances as well as safe ones.

(46) If repairs have to be made on prints that have arrived from the exchange ostensibly in good condition, their character and location should be noted and a memorandum sent down to the theatre manager giving the time devoted to making the repairs. A copy of this memorandum should be sent to the exchange manager and if the repairs have been extensive and considerable time devoted to making them, a bill to the exchange would not be out of order.

(47) Whenever an exchange fails to heed the complaint of the theatres and continues to ship out film without the proper inspection and repairs, the matter should be brought to the attention of other agencies which will compel the exchange to handle its film properly: to the local projection union, to the local theatre managers' organization, to local municipal authorities and to the home office headquarters of the film company.

Keep Film Stored

(48) All film not running through the projector or

upon the rewinder should be kept stored away in film cabinets in the order in which the reels are to be used. Local ordinances everywhere demand that the film be stored when not in use and it is also a strict Fire Underwriters' requirement.

How to Rewind Correctly

(49) It requires approximately eleven minutes to project 1,000 feet of film and twenty-two minutes to project a 2,000-foot reel. Film can be safely rewound at about twice its projection speed—but no faster. Projectionists have become accustomed to rewind film at high speed and the habit is hard to break. Generally speaking, 1,000 feet of film should not be rewound in less than six minutes.

(50) At that speed the rewinding instrument will operate safely without supervision. The rewinder is an important instrument. (51) It should be located in the projection room proper and as near as possible to the film storage cabinet. (52) All so-called safety laws to the contrary, there is no added protection gained by placing the rewinder in a separate compartment. As a matter of fact, the result is sometimes precisely the opposite, particularly in theatres with but one man in the projection room.

By means of properly fused port fire shutters all communication between the projection room and the theatre auditorium, in the event of fire, can be shut off tightly and automatically in a few seconds. If proper arrangements have been made to exhaust smoke and gas as soon as it forms it is likely the audience will be totally unaware of trouble except for the dark screen. But if the rewinder is located in a separate room the chances of fire are greater because the projectionist will often be out of sight of the projectors, despite regulations to the contrary, rewinding his film.

Even where there are two men in the projection room, both may be out of sight of the projectors, examining film on the rewinder. The same procedure, when the rewinder is in the projection room, makes for real safety because the projectors are always in full sight but a few paces away.

Rewinder Details

An opening approximately 2.5 inches by 4.5 inches should be cut clear through the rewinder table top and covered, flush with the table top with a piece of thick ground glass. (53) If no ready ground glass is available, an ordinary piece of glass may be ground down by rubbing it vigorously with No. 00 or 0 emery paper or cloth.

Under the glass install a low c. p. electric light globe operated by a switch conveniently located near by. It will aid in making good film splices. It is not essential equipment in connection with a rewinder but is sufficiently helpful to justify its addition.

(54) If the rewinder you use is not a single unit, that is, if both elements are not mounted on a single metal base, be sure that you set them up in perfect alignment so that the reels are in perfect alignment, too. This is an item that is neglected by many projectionists who should know better.

(55) If the rewinding speed is high, the reels imperfect or the rewinder elements out of line, the film will suffer heavily. When the reels are out of alignment the edge of the film will rub against the reel sides with sufficient force to tip one side of the film up until the sound band is abraded and permanently injured.

It is best to use a single unit rewinder to avoid all possibilities of poor alignment. If separate rewinder elements must be used at least make sure that each is securely fastened to the table top in absolute alignment with the other.

(56) The rewinder element, from which the film is being unwound must be equipped with a brake strong enough to make the film rewind snugly though not too tightly. No rule for the amount of braking power can be made; the projectionist must determine that for himself. If the rewinder is an enclosed unit, a brake is always part of its equipment. If separate rewinder ele-

ments, mounted on a table top, are used, the projectionist can make a brake out of simple materials. (57) He should also provide means for the automatic opening of the rewinder motor circuit switch as soon as the film has been wholly rewound. Otherwise the film will continue to run until someone stops it—the end of the film, in the meanwhile, slapping around and being injured. In projection rooms around the country there are examples of rewinder brakes, automatic motor switches and other projection accessories that should be the envy of all engineers and manufacturers.

An Ideal Rewinder Arrangement

(58) Messrs. Slagle and Seckle, projectionists at the Palace Theatre, Marion, Ohio, have what is generally considered an ideal rewinder, built by themselves, and in daily use for more than six years. It operates at the

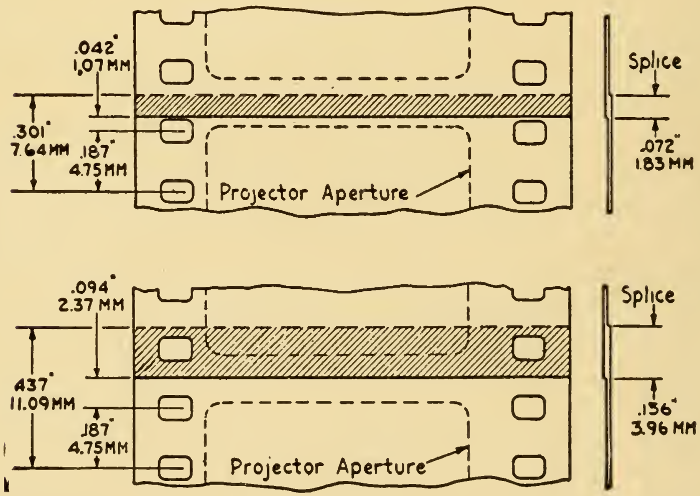


Fig. 60.—Showing properly made splices. Upper illustration is a regular positive splice; lower, is a full hole positive splice.

rate of 1,000 feet of film in six minutes; by shifting belts, when necessary, it will rewind at a much faster rate, but always smoothly and efficiently. This is how they built it.

Study Fig. 61. The rewinder elements are of the Simplex type. A is the rewinder table top of fairly heavy lumber. C an iron shelf bracket, obtainable at any ten-cent store. D, iron switch box of the flush wall type containing a toggle type switch, single pole, flush type. E is an extension measuring 3/16 inch in diameter by 1¼ inches long, threaded at one end and screwed into a hole at the end of the switch handle. It provides the necessary leverage to enable spring I to open the switch. F is a small coil spring 3/16 inch by 2 inches designed to act as a shock absorber. G is a round belt about ⅜ inch in diameter. H is a pulley attached to the rewind rear or dead element shaft. It is 3½ inches in diameter and should have a fairly wide groove to enable proper operation of belt G. I is a coil spring ⅜ inch in diameter by 5 inches long. It should exert a five-pound pull when stretched. J is a box, or other support for box D. K is a pulley on the driving element of the rewinder, 8 inches in diameter. L is a two-step idler pulley, the small element 1¼ inches and the large one 4½ inches in diameter at the bottom of the groove. All pulley diameters are measured at the bottom of their grooves. M is the motor pulley 1¼ inches in diameter with a speed of 1750 rpm.

Fig. 61 shows the reels in position for rewinding, the arrows indicating direction of rotation. The friction of belt G will exert a pull against spring I and stretch it. The switch is closed by moving the handle extension E back, the action stretching spring I. There must be enough friction between belt G and pulley H to keep the spring I stretched, the switch remaining in closed position as long as pulley H rotates.

When rewinding is completed the film pulls loose from reel A, whereupon it stops and so does pulley H; automatically spring I contracts, pulling switch handle E to position "off"; as a consequence the motor circuit is broken and the whole thing stops.

Both rewinder shafts must be long enough to enable the proper mounting of pulleys H and K. It is quite easy to make longer shafts by securing a length of

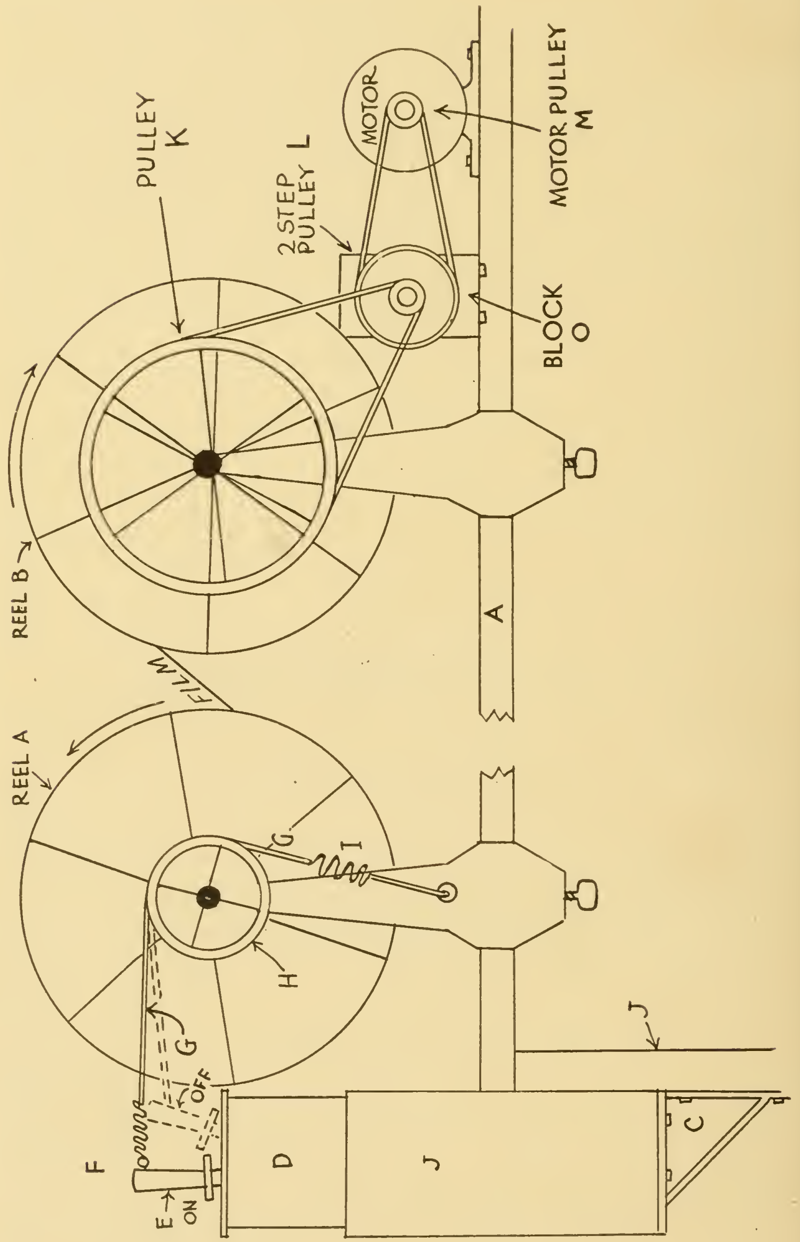

PULLEY K
MOTOR
MOTOR PULLEY M
2 STEP PULLEY L
BLOCK O
REEL B
FILM
REEL A
A
G
I
H
G
OFF
ON
E
F
D
J
J
C

FIGURE 61

round 5/16 inch cold rolled steel or drill rod. Remove the old shafts and make the new one like them except in length. Pulleys can be secured by your hardware dealer, or can be made for you by your local machine shop. To increase the rewinding speed in an emergency it is only necessary to have an extra belt to reach directly from motor pulley M to pulley K.

(59) Immediately above the rewinder stretch a short length of film connected with the port fire shutter master control. A fire at the rewinder will burn the bit of film, thus instantly releasing the fire shutters.

Calculating Rewinder Pulleys

(60) As already noted, rewinding speed should not exceed the rate of six minutes for each 1,000 feet of film. The rule for computing the speed of pulleys is as follows: multiply the speed of the driving pulley per minute by its diameter and divide the sum by the diameter of the driven pulley. The result is the speed of the driven pulley.

The circumference of the driven and driver pulleys may be used for the calculation instead of diameters. The result will be the same. If we have a motor pulley two inches in diameter (diameter of the face of pulley) running 1,400 revolutions per minute, and propose to drive a countershaft pulley six inches in diameter, you have 2 × 1,400 = 466.6 revolutions the counter shaft would run per minute. If we then propose to drive a 10-inch diameter pulley mounted on a rewinder with a two-inch diameter countershaft pulley, the reel upon which the film is being rewound would run 466.6 × 2 = 933.2 ÷ 10 = 93.383 revolutions per minute.

Stated in proportions—the diameter of the driver pulley is to the diameter of the driven pulley as X is to the revolutions of the driver pulley. For the solution, multiply two extremes (end quantities) and divide by the known middle number. Result will be the revolutions per minute of the driven pulley.

Film Reels for Shipment

(61) To protect film while in transit reels must be used that will not bend out of shape easily. Wire reels are excellent in this respect. They are neither rough nor sharply pointed anywhere and do not damage the film. Such reels must also be quickly attachable and detachable with respect to the magazine shaft locking device, and exceptionally strong where it engages it. They must permit the film to be attached to the hub easily and allow it to pull loose easily. They should be as light in weight as is consistent with strength and rigidity.

Projection Room Reels

(62) Each exhibitor should provide a full set of reels to be used in the theatre only during projection. These may be substituted for the exchange reels either when the film is being examined before projection or during projection. Film can be rewound on their shipping reels either during the last projection or when rewinding for shipment after the last projection.

Projection room reels should be kept in good condition and repaired or replaced at the slightest sign of imperfection. No conscientious projectionist, unless he were compelled by conditions or an indifferent manager, would use crooked or damaged reels, risking injury to prints. It is wise to stamp all theatre reels with the name of the theatre and to guard against sending them to the exchange by mistake.

The DeVry spring steel reel, recently put on the market, possesses the attributes of a good, firm, durable projection reel and deserves the consideration of theatre managers and projectionists.

Footage Capacity of Reels

(63) Taking all arguments into consideration, there is a great deal to be said in favor of the 2,000-foot reel both for shipping and for projection. Projectionists have agitated in its favor for a long time and despite objections many continue to use the larger reel.

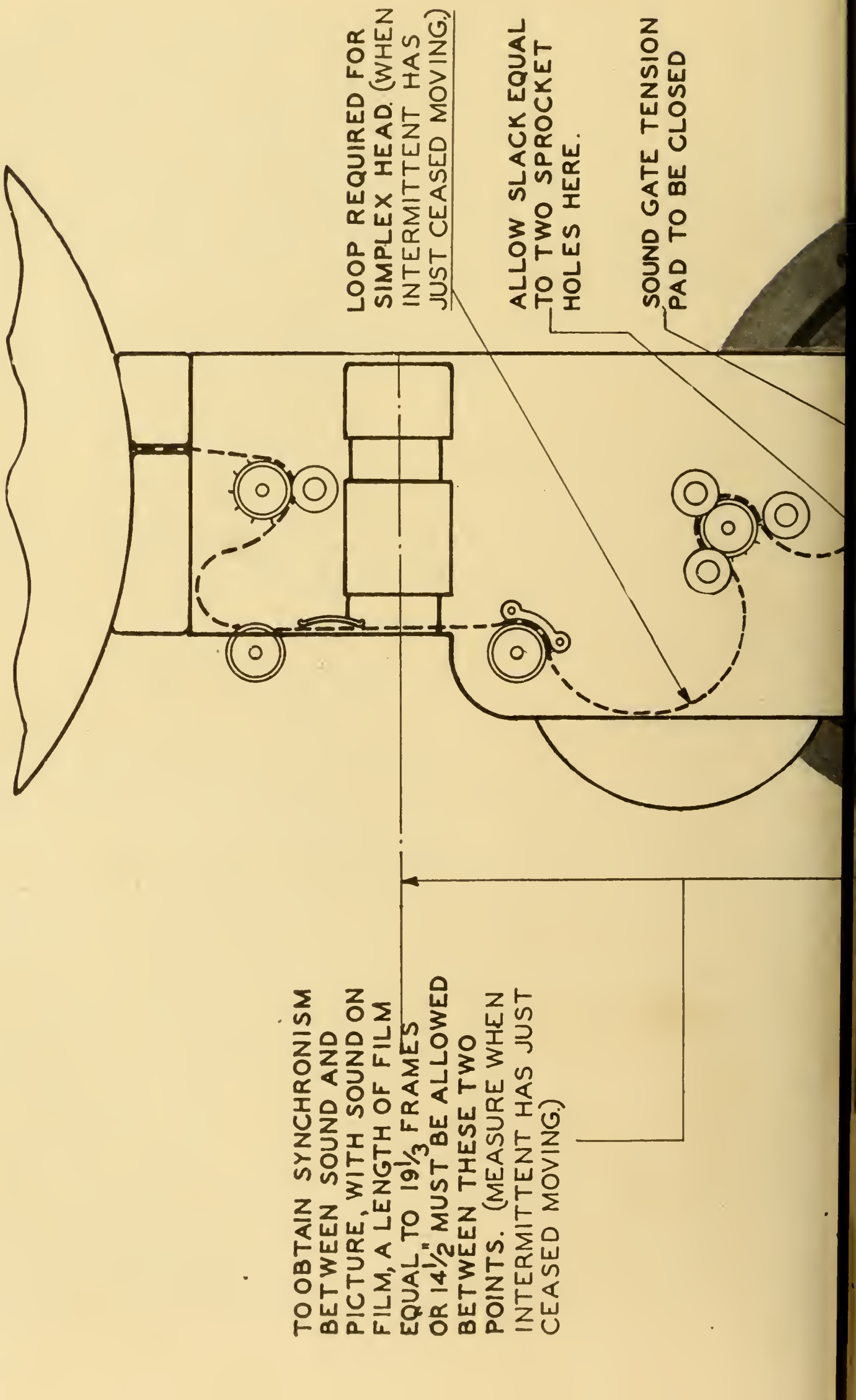
(64) The exchanges, however, still consider the 1,000-foot reel more desirable. They fear the weight of the added film on the larger reel will make damages more likely during transit. Increased weight calls for heavier shipping cans, an investment they would rather not make. They claim also, and rightly, that as weight of more film is added to rolls of old dry film, the film will be injured during projection. And there are further objections.

(65) Projectionists, on the other hand, hold that projection today is complicated and difficult and should be made as easy as possible whenever the opportunity affords itself. This is particularly true in theatres where only one projectionist is on duty at a time. At every change-over he is away from the working projector, threading the idle one, adjusting its carbons and making other preparations—a dangerous situation which the 2,000-foot reel reduces by half.

How to Estimate Footage in a Film Roll

(66) How may the footage in a roll of film be estimated?

Because film varies between 5½/1000 and 6/1000 of an inch in thickness and because the tightness of the winding varies in different rolls of film, it is possible to calculate the footage contained in any roll with only approximate accuracy. However, it may be estimated as follows, using inches for all measurements: (67) First add the circumference of the opening (reel Hub) in the center to the outer circumference of the film roll. Divide by 2. This will give the average length, in inches, of layers of film in the roll. Next, measure from outer to inner diameter of the film roll and divide by 5¾ (a compromise between the film thickness of 5½/1000 and 6/1000 of an inch). Result will be the approximate number of layers of film in the roll. Multiply this by the average length of the layers and divide by 12 to get the number of feet. Final results will be footage of film in the roll as nearly as it can be arrived at by computation.


LOOP REQUIRED FOR SIMPLEX HEAD. (WHEN INTERMITTENT HAS JUST CEASED MOVING.)
ALLOW SLACK EQUAL TO TWO SPROCKET HOLES HERE.
SOUND GATE TENSION PAD TO BE CLOSED
TO OBTAIN SYNCHRONISM BETWEEN SOUND AND PICTURE, WITH SOUND ON FILM, A LENGTH OF FILM EQUAL TO 19⅓ FRAMES OR 14½" MUST BE ALLOWED BETWEEN THESE TWO POINTS. (MEASURE WHEN INTERMITTENT HAS JUST CEASED MOVING.)

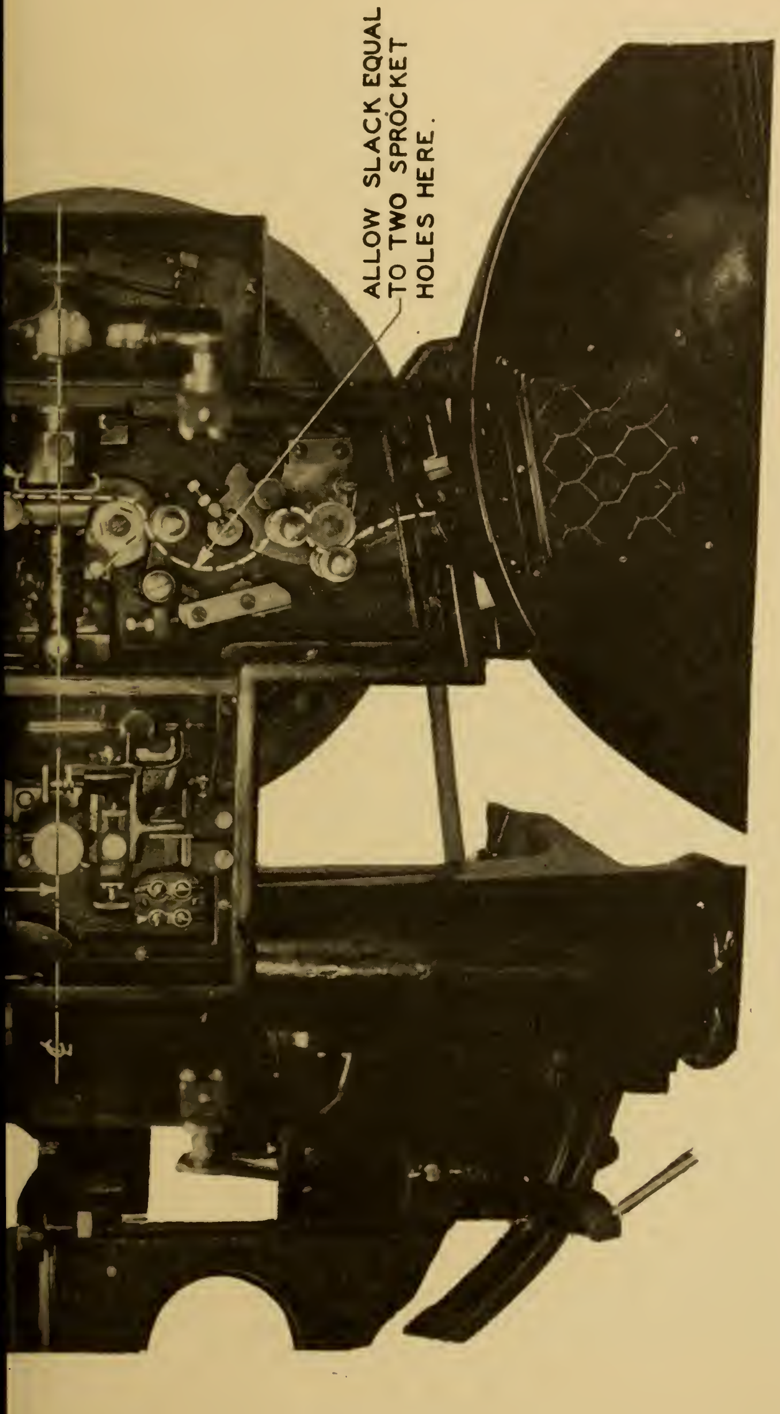


FIG. 52.—Path of film through Simplex projector and 206-A Western Electric sound head.

Measuring Film Accurately

(68) To measure the length of a reel of film accurately count the rotations of the projector mechanism crank shaft. Exactly one foot of film is passed with each rotation. Film measuring devices may be purchased from supply dealers.

Removal of Emulsion

(69) To remove the emulsion from the film, first soak it in a bucket of warm water to which has been added all the ordinary washing soda it will absorb. Let the film soak until the emulsion has become soft, after which it may be washed or rubbed off. Afterward rinse the film thoroughly in clean, warm water. Soaking for a long time, over night, for example, will do no harm.

Cleaning Film

(70) Film may be cleaned with a soft cloth saturated with commercially pure carbon tetrachloride. Be careful not to scratch the film. The carbon tetrachloride must evaporate thoroughly before the film is rewound. If this is not done, the tetrachloride will bleach the emulsion away.

(71) Film is often cleaned with gasoline or benzine, but for several reasons we do not advise it. For one thing the film will curl badly. It may be harmed in other ways. As a rule it is best to leave the responsibility for cleaning the film to the exchanges where it should be done. They have the proper equipment and the staff to do it properly. The theatre should insist on receiving clean film from the exchanges.

Rain

(72) The effect termed "rain," which appears on the screen when old film is used, is caused by scratches in the film emulsion that have filled with dirt and thus have become more or less opaque.

The projectionist himself should object to receiving oil-smeared film from an exchange. It is right that he should do so, but he must remember that the oil got there in the first place either through the carelessness of some projectionist somewhere or by the refusal of a theatre management to make necessary projection equipment repairs.

(73) Some projectors have a slight oil leakage from the intermittent oil well. Unless the projector parts are badly worn and need immediate replacement, the projectionist, by exercising a little care, can keep the oil from reaching the film. It is generally done by a wiper located between intermittent sprocket and the oil well. It is not an easy thing to set up, but many projectionists have done it successfully.

Standard Release Print

(74) The change-over cue in standard release prints consists of a black dot printed in the upper right hand corner of four consecutive frames of every print, the first of which is located 22 frames from the end of the picture—provided no frames beyond it have been eliminated in doubling up or in making a splice. On light backgrounds the black dot serves, but on dark backgrounds the black dot is or should be surrounded by a thin white line in order to make it more visible.

(75) In locating the change-over cue 22 frames from the end it was assumed that approximately one-half second would be consumed in operating the dowser when the cue showed up on the screen. If the change-over is to be perfect it is essential that there be no delay. The projectionist must act instantly when the cue appears on the screen.

(76) The projectionist may help himself to spot the cue marks by setting up a pad of paper near the observation port and during the first projection of the day make note on it of the action just preceding the cue in each read, "Girl approaches well," which is enough to enable the projectionist to locate the cue mark for an exact change-over.

The Motor Cue

(77) The cue to start the idle projector motor con-

sists of a black dot exactly the same as the change-over cue, printed on the upper right hand corner of four consecutive frames, the first of which is twelve feet and six frames from the end of the picture. (78) This distance enables the projectionist to make due allowance for variable speed of pick-up in different motors. The slowest may use almost the whole distance between the motor and the change-over cue marks. Every projectionist should test his motors and make the necessary allowance.

(79) Since the motor start cue is twelve feet and six frames from the end of picture, at 90 feet per minute this would consume approximately eight seconds of time. The problem is to ascertain just how many feet of film each motor, starting from dead position, will pick up in eight seconds, since that will be the actual motor-start footage for that particular projector, and must be considered when threading up. In other words, if the first projector picks up in eight feet, you must thread with the motor-start frame four feet and six frames past the aperture. If projector No. 2 only picks up twelve feet and six frames in the same interval, then you must place the motor-start frame over the aperture.

To Ascertain Motor-Start Footage

(80) In an empty theatre, place the footage frame marked No. 11 over the aperture. With one projector working, start the other the instant the motor-start cue appears. Operate the dowser the instant the change-over cue comes through. Should there be a lapse on the screen between the two reels, try again, this time placing frame No. 10 over the aperture; continue the operation until you have found at exactly what point the effect is perfect. This indicates exactly what frame to place over the aperture each time you thread that particular projector.

To avoid error by the relief men it is best to record the pick-up data on a couple of gummed stickers in some visible spot on each projector mechanism.

(81) Except for change in voltage (which does

occur in some places and cannot be guarded against), and possibly a weakening of the motor itself, which is unlikely, the pick-up of any projector motor, once calculated, will always be the same.

(82) The process must be repeated for each motion picture projector you have, since there may be decided variations in pick-up speed in projectors located side by side.

(83) To start close the switch of the idle projector motor when the motor cue appears. The instant the change-over cue appears on the screen operate the dowser.

Checking Synchronism

(84) The standard release may be used for checking synchronism. Any variation in the size of the loop between the projector and sound head aperture will destroy synchronism.

When the start-frame is threaded over the aperture and the loops are of correct length, there will be a diamond mark over the sound aperture. The diamond mark is located twenty frames in advance of the start-frame. (85) For perfect synchronism examine the location of the diamond mark at every threading. Turn the flywheel until the right motor-start frame is over the aperture. Experience will enable the projectionist to judge the loop size very accurately.

Disc Record Threading

(86) To thread for disc, place the needle on the record at the synchronizing mark. Thread the projector with the motor-start mark over the aperture. Rotate the flywheel until the change-over frame appears at the aperture, meanwhile counting the revolutions of the turntable in order to short-cut the process next time.

Upkeep of Standard Release Print

(87) Projectionists who take pride and interest in their work will do nothing to diminish the effectiveness of the standard release print. Every frame cut away

for one reason or another reduces its usefulness in the projection room. With the general use of the 2,000-foot reel there will be little occasion to manhandle the release print. Remember that it is 100 per cent effective only so long as it remains in its original condition and occupies its original position with relation to the beginning and end of the reels.

THE MOTION PICTURE PROJECTOR

1. Why is a forward and back rocking movement of the projector stand objectionable?
2. Must the supporting floor be without movement or vibration?
3. How should the supporting stand be secured to the floor?
4. How should anchor bolts be embedded in a new floor?
5. What adjusting facilities should the supporting base provide?
6. What adjustments must the tables carrying lamphouse and mechanism provide?
7. What fault in the screen image does the audience discern if the pedestal is out of level sidewise?

THE LAMPHOUSE, PAGE 210

8. How much ventilation does a lamphouse require?
9. How is lamphouse ventilation provided?
10. Why is lamphouse ventilation so important?
11. Is a screen necessary over the inner end of the lamphouse vent pipe?
12. Is the lamphouse vent pipe necessary when a Mazda light source is used?
13. Should the removal of carbon chips and other matter be made convenient?

THE DOWSER, PAGE 211

14. What advantages are gained by locating the dowser between the light source and the collector?
15. How near the collector should the dowser be?
16. Why is a heavy dowser blade best?
17. Are some lamphouses equipped with both inside and outside dowsers?
18. Where should the dowser be located in a Mazda or low intensity reflector type light source?

19. What precautions are necessary in handling dowsers in high intensity light sources?

Inspection, page 212

20. How often should condensers be inspected and cleaned?
21. How often should the interior of lamphouses be inspected and thoroughly cleaned?
22. What happens when the wires inside the lamphouse become over-heated?
23. How are wires inside the lamphouse tested for satisfactory condition?
24. Does discoloration of the copper under insulation condemn a wire?
25. Why and how often should wire connections inside the lamphouse be taken apart and cleaned?

Lamphouse Support and Alignment, page 213

26. How much forward and backward movement should the lamphouse supporting rods supply?
27. Should provision be made for side movement of lamphouse?
28. Must the condenser or mirror have means for adjustment upward, downward and sidewise?

The Intermittent Movement, page 214

29. How is the rotating shutter and intermittent movement locked together to work in exact synchronism?
30. What is accomplished by each cycle of action of the intermittent movement?
31. At 90 feet per minute projection speed how often is the projector aperture covered with a film photograph?
32. How accurate must the action of an intermittent movement be?
33. How closely are intermittent parts fitted together?
34. What parts make up the standard intermittent movement?
35. Explain the action of an intermittent movement.
36. What is meant by an intermittent movement being "on the lock"?

37. Is the speed of the intermittent sprocket unvarying from time of starting to time of stopping?
38. By what process are intermittent parts finished?
39. What parts of modern intermittent movements are hardened? Why are intermittent sprockets no longer hardened?
40. How is any inaccuracy in the intermittent movement that effects the intermittent sprocket magnified on the screen?

Intermittent Movement Lubrication, page 217

41. What is required to keep the intermittent movement properly lubricated?
42. How is the time for draining oil wells determined?

Intermittent Sprocket, page 218

43. What is the accepted speed of intermittent action?
44. How fast is film fed down to and taken away from the intermittent sprocket?
45. How is the intermittent action of the film made possible?
46. Describe the action of the upper and lower loops and the film as a whole.
47. How often and in what manner should the intermittent sprocket teeth be examined?

Lost Motion in Intermittent Sprocket, page 220

48. How closely must cam A be adjusted to star B?
49. What is the test for correct adjustment between star and cam?

Replacement of Intermittent Sprocket, page 220

50. What happens if the sprocket is too tight or too loose upon its shaft?
51. How does the projectionist proceed to install an intermittent sprocket?
52. Describe the correct procedure in installing a new sprocket on a shaft.
53. How can a V block be made?

Aperture Plate Tension, page 222

54. What is the effect of insufficient tension at the aperture?
55. What is the effect of too much tension at the aperture?
56. What tension at the aperture imposes the least strain upon both the film and projector mechanism?
57. Describe a practical method of adjusting tension at the aperture without resorting to special tools.
58. How do you determine whether or not the tension shoes on each side are exerting the same pressure?
59. Why does good definition require that the surfaces of the tension shoes and the aperture plate tracks be perfectly level and flat?
60. Will worn tension shoes and aperture plate tracks buckle the film as it lies over the aperture?
61. How often should tension shoes or aperture plate tracks be tested for flatness?
62. What must be guarded against in installing new aperture plate tracks (or a plate and tracks in one unit)?

The Rotating Shutter, page 225

63. What is "persistence of vision"?
64. What is the only thing that is visible to the eye on a motion picture screen?
65. What would happen were a picture projected without the rotating shutter?
66. Does the shutter master blade cut all light from the screen when the film is moving over the aperture?
67. Why has the rotating shutter more than one blade?
68. Explain the illusion of continuity of motion.

Setting the Shutter, page 226

69. Describe the process of setting a shutter.

Rotating Shutter and Intermittent Speed, page 227

70. What is the relation between the speed of the intermittent movement and the width of the rotating shutter master blade?

71. What is the relation between intermittent speed and the light that is allowed to pass by the rotating shutter?
72. What are the limiting factors in intermittent speed?

The Modern Rotating Shutter, page 228

73. Did the old type of rotating shutter have any effect on the heat applied to the film?
74. What damage did the high temperature at the aperture do?

The Disc Type Rear Shutter, page 228

75. How far is the rear shutter located from the aperture?
76. What is the relation of the rotary speed of the master blade edges to the distance between the shutter shaft and the center of the light beam?
77. Though the time interval of cutting the beam is short why is its effect considerable?
78. May either blade of most disc type rear shutters be used as the master blade?
79. Do rear shutters create an air current at the aperture and thereby reduce aperture temperature?

The Horizontal, Cylindrical Type Shutter, page 230

80. Describe the horizontal cylinder type rotating shutter.
81. Describe the location and housing of the horizontal, cylindrical type shutter.
82. Why does the ratio between width and speed of the disc type shutter blades not apply to the Motiograph shutter?
83. Does either blade of the Motiograph shutter act as both, master and cut-off blade?
84. How does the Motiograph shutter create air currents at the aperture?
85. In which direction does the Motiograph shutter move the air?

Regulating the Front Shutter, page 231

86. What is meant by "point of aerial image"?

87. Is it important that front shutters be located at the point of aerial image?
88. What effect does the blade produce at the point of aerial image?
89. Is there any advantage to be gained in locating the shutter at the point of aerial image unless the width of the shutter master blade is reduced?
90. Describe a practical method of testing the width of master blade.
91. If the width of the master blade is reduced is it necessary to reduce the width of the cut-off blade?

The Rear Shutter Blades, page 233

92. In what two problems of the rear shutter is the projectionist most concerned?
93. In testing the width of the shutter blade what should be used?
94. How far do local conditions control the adjustment of the rear shutter blade?
95. How may beam depth at shutter position be ascertained?
96. What is meant by the "effective beam"?
97. How would you lay out the effective beam on paper?

The Gear Train, page 235

98. What functions does the gear train perform?
99. How much lost motion is permissible in a gear train?
100. What maximum amount of wear is permitted in the gear train?
101. How may lost motion in a gear train be measured?

Gear Lubrication, page 236

102. What is the best lubricant for projector gears?

Lubrication of Bearings, page 237

103. How much oil is necessary to adequately lubricate any projector bearing?

Sprocket Idlers, page 237

104. What function do sprocket idlers perform? What two different elements are used to hold the film to the sprocket?
105. At what distance should idlers be spaced away from the face of the sprocket?
106. How are sprocket idlers spaced the correct distance from the face of the sprocket?
107. What may happen if the sprocket idler is too near or too far from the face of the sprocket?
108. Must the ends of sprocket idlers be equi-distant from the face of sprocket? What happens if the distance is unequal?
109. What may happen if the sprocket idler rollers are not properly lubricated? How often should they be inspected?

Upper Magazine Tension, page 238

110. Why should tension be applied to the reel in the upper magazine of a projector? How should it be applied?

Lower Magazine or Take-Up Tension, page 238

111. Why must slippage be provided for the lower reel?
112. How much tension should be applied to the slippage device?
113. Will too much take-up tension damage the film? Will it cause excessive wear of the lower (hold-back) sprocket?

Magazine Rollers and Fire Trap, page 239

114. How often and for what purpose should the magazine rollers and the fire trap be inspected?
115. Should the magazine fire trap rollers be lubricated?

The Path of Film Through the Projector Mechanism, page 239

116. How often should the path of the film through the projector mechanism be inspected especially when old films are used?
117. How often should the path be inspected when using new films?

118. How often should the aperture plate track and tension shoe bearing surface be inspected?
119. It is essential that the film pass through the projector mechanism in a perfectly straight line?
120. By what means is the film guided past the aperture?
121. How may the straightness of the film path be judged? What rule should be observed if it is necessary to install a new lateral guide roller?

Automatic Fire Shutter, page 240

122. Of what does an automatic fire shutter consist?
123. Are all fire shutter mechanisms the same? What care do they require?
124. At what minimum projection speed should the fire shutter rise and fall?
125. How often should the operation of the fire shutter be checked?
126. What length of film suffices for the loop movement?
127. How may the required loop size be judged? What is generally regarded as the best loop size?
128. What items should have especial attention and consideration in the care and operation of the projector?

CHAPTER VIII.

THE PROJECTOR

Nothing is more important to an understanding of the methods and practices of good projection than a knowledge of the projector. Projectionists often shift from theatre to theatre and encounter different types of projectors which they are expected to operate efficiently. It is easy to secure instruction books from the various manufacturers by simply writing for them. It is considered sufficient to discuss here only those fundamentals which apply equally to all makes.

The Supporting Base

All projectors require a supporting base of sufficient strength and rigidity to support the lamphouse, mechanism, sound head, etc., and to hold them without vibration. Its contact with the floor must have sufficient area to insure this condition, assuming the floor itself to be without movement or vibration. (1) In considering the projector support it must be remembered that any vibration of the projector backward and forward upon its base will be magnified many times upon the screen, the magnification increasing as the distance of the lens to the screen increases.

(2) Because absolute rigidity is required, the floor itself must be without vibration and the projector supporting stand must contact it securely by means of anchor bolts.

(3) When building a new floor, the kind and model of projector should be decided upon in advance, a template made and the anchor bolts suspended therein, with heads not less than four inches below the floor surface. The concrete is then carefully and solidly packed around

them, forming an ideal anchorage for the projectors.

(4) It is possible to embed anchor bolts in a cement floor that is already laid. Drill holes four inches deep and of sufficient diameter to just admit the heads of the anchor bolts, which need only be one-eighth inch larger than the bolts themselves. Then, with a small, round-nose or diamond point cold chisel, cut small holes around the sides of the bolt holes or roughen their sides by gouging out pieces of concrete. This helps the metal filling to be well anchored.

Next set the anchor bolts in place, heads to the bottom, and fill the space around them with molten lead or babbitt.

(5) The supporting base must have an up-and-down adjustment with a proper locking device, for raising or lowering the projector mechanism. (6) Means must also be provided by which the table supporting the lamphouse and mechanism may be tilted and locked rigidly in position to provide an upward projection angle of not less than 10 degrees and a downward angle of not less than 25 degrees. Greater projection angles are used, but it is poor practice.

In the supporting base of the pedestal type, provision should be made for carrying the various circuit wires upward through the supporting column. It is not essential, but makes a neater job.

(7) The projector must be set perfectly level sidewise, else the screen image will itself be out of level.

The Lamphouse

(8) Except in case of the mazda light source, the lamphouse should have maximum ventilation without disturbing the light source. It is a good general rule to follow because it reduces the room temperature as well as the temperature of the lenses, mirrors, wires and mechanisms inside the lamphouse.

(9) Lamphouse ventilation should be through a metal pipe having riveted or otherwise well secured joints. The pipe should connect either with the main theatre ventilation system or, preferably, directly with

the open air. It should be thoroughly insulated from all inflammable material and provided with an adjustable damper—since constant adjustment of the draught is essential to good operation of the light source.

(10) Lamphouse ventilation helps to reduce projection room temperature in summer and in all seasons in warm climates. High temperature inside the lamphouse is hard on the mechanism, causing it to deteriorate much more rapidly than would be the case at moderate temperature.

(11) It is not at all necessary that the lamphouse vent pipe be covered with a screen. Such sparks as pass into it are extremely light and harmless. The objection to a screen—it must be of fine mesh to be effective against sparks—is that it would quickly become clogged with carbon ash, and interfere with or entirely stop all ventilation. If you have a vent-pipe screen, we advise its removal unless local authorities object.

(12) Where Mazda serves as the projector light source there is no need for a vent pipe, since it generates no gases and relatively little heat. It is enough to leave the vent in the top of the lamphouse open.

(13) Every lamphouse should have convenient means for the removal of carbon chips and other refuse from the lamphouse floor. The workmanlike projectionist keeps his lamphouse scrupulously clean.

The Dowser

(14) With all straight high intensity light sources a dowser blade should be located between the light source and the condenser collector lens. When the arc is struck, all high intensity light sources throw off incandescent particles of carbon which will quickly destroy the polished surface of the collector lens if it is not protected.

Regardless of the type of arc light source, if a condenser is used in front of the arc there should be a dowser blade of substantial thickness (15) located as close to the collector lens as is practicable. Not only does this blade protect the lens from flying particles of carbon when the arc is struck, but it is also, to a considerable extent, a protection against the effects of sudden temperature changes. It has saved many a lens from cracking.

(16) The high intensity dowser blade should be of substantial thickness to withstand the extremely hot light source. A thin blade is useless against the heavy and (at high amperage) long tail flame of the light source. It is either warped or wholly destroyed.

(17) Some lamphouses are equipped with two dowsers, one located between the light source and the condenser and the other in the lamphouse cone. It is presumed to be a double protection for the condenser against sudden temperature changes.

(18) Dowsers for the low intensity reflector type and the mazda type light sources may be located in the lamphouse cone.

(19) The dowser must be kept closed when striking a straight high intensity arc, and kept closed until the arc is burning normally. Never open an inside dowser after pulling the light source switch until the lens has had time to cool off somewhat.

Inspection

(20) The condenser lenses, particularly the collector lens of a two-lens condenser, or the mirror collector-converger, are exposed to deposits deriving from the gases generated by the arc or carbon dust. Other particles in the air also collect upon them. Therefore they should be inspected and thoroughly cleaned each day, either by washing with soap and water, followed by a thorough rinsing and polishing, or by wiping with a cloth wet with an equal mixture of grain alcohol and water, followed by thorough polishing. Where a high amperage arc is used the collector lens or mirror should be wiped off after each show. (21) The whole lamphouse should be inspected and thoroughly cleaned once a week at least, but more often in theatres of continuous performance. Frequency of cleaning is dependent to a considerable extent upon the kind and power of the light

source used. Every morning the lamphouse floor should be cleaned of all refuse.

The frequency of examination of wires inside the lamphouse is dependent upon how heavily loaded they are, and what the normal temperature is inside the lamphouse. If the temperature is excessive, then, since the resistance of copper increases with increased temperature, the wires should be examined frequently. (22) If the wires are heavily loaded and the lamphouse temperature is high, the wires become more or less oxidized, and in this condition their resistance is very high and in danger of fusing at any moment.

(23) The condition of the stranded (asbestos covered) wires may be tested, roughly, by their resistance to bending. If they are stiff and hard to bend they are in fair condition; if they bend easily, then split the insulation and examine them. If they are dark brown clear through, replace them. Unless this is done, not only will power be wasted by their excessive resistance, but they will certainly fuse later and stop the show until replaced.

(24) If the wire shows dark brown on its outer surface, is stiff, and is copper-colored inside, it is still serviceable. The reference is to stranded asbestos covered wires only.

(25) At reasonable intervals—about once every two weeks—all wire connections (binding posts, etc.) should be taken apart and cleaned. Scrub the contact surfaces well with crocus cloth or 00 sandpaper. Very often a connection will form a thin, almost invisible scale of high resistence. This happens mostly in places of high temperature such as lamphouses, where it is good practice to clean all wire connections once a week.

Lamphouse Support and Alignment

(26) The rods upon which the lamphouse is mounted must have sufficient movement to enable the projectionist to locate the mirror or condenser at the proper distance from the aperture required by the optical system. (27)

Provision must also be made for side movement of the lamphouse.

(28) The optical axis of each element of the optical train must be centered exactly upon the optical axis of the system considered as a unit. The plane of each element must be perpendicular (at right angles) to the optical axis of the train. This requires means for adjusting the condenser or mirror up, down and sidewise.

In a perfect alignment, a thread stretched tightly from the exact center of the condenser or mirror to the exact center of the front end of projection lens, would be exactly in the center of the rear end of the projection lens and the aperture. If the elements of the optical train are not in alignment then a portion of the light never reaches the screen. Sometimes, too, the bases on which the projector mechanism and the lamphouse rest are not not in proper alignment, affecting the alignment of the lamphouse optical system and of the projector mechanism. These are difficult things to check unless the proper tool is available. Fortunately the SMPE Projection Practice Committee recently developed an instrument for lining up the whole projector optical train. It is inexpensive and every projectionist should secure it, either personally or through his theatre management.

The Intermittent Movement

(29) The intermittent movement and the rotating shutter are so locked together by a train of gears that the shutter must rotate exactly once each time the intermittent movement acts, and by so doing moves the intermittent sprocket precisely one-fourh of a revolution.

(30) This cycle of motion displaces the film photograph from the aperture and substitutes the next succeeding one, the whole cycle lasting one twenty-fourth of a second. (31) In other words, it occurs twenty-four times per second, during which each one of twenty-four photographs is successively projected to the screen. (32) This accuracy of action makes certain that each photograph or "frame" will remain perfectly still and

perfectly flat over the aperture during its period of projection, and will, within one ten-thousandth of an inch, occupy precisely the same position occupied by every other photograph of the series.

(33) To make the intermittent movement function with such extreme accuracy (33) all vital parts are fitted together with less than 1/10,000 of an inch tolerance of error.

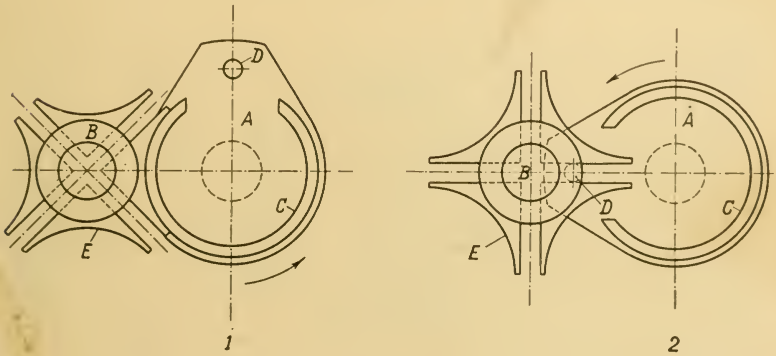


FIGURE 62

In Fig. 62 we have two line drawings of a standard intermittent movement such as is now universally used in modern motion picture projectors. Incidentally, by means of a differently designed and constructed movement, the Powers intermittent performs precisely the same functions as does the standard type of Geneva movement, though Powers projectors are no longer widely used.

(34) Figures 62 and 63 illustrate the standard type of Geneva movement. It consists of a maltese cross of steel, B, commonly referred to as the "star," and steel cam A, upon which is mounted a master pin of steel, D, which drives the "star." This cam also carries a flat circular surface, C, by means of which the star, and therefore the intermittent sprocket which is mounted upon its shaft, are locked immovably while standing still—that is, in the interval the photograph is poised over the aperture and is being projected to the screen.

(35) The action is as follows: In part 1, Fig. 62, we see the two parts, cam A carrying the master pin D, which is in continuous rotation so long as the projector is in motion, and star B, which is standing still—one of its four curved surfaces E, being in contact with the surface of cam ring C, in which position it is evident star B cannot be rotated. It must, in fact, remain perfectly still until the two surfaces are released. (36) In this condition the movement is said to be "on the lock."

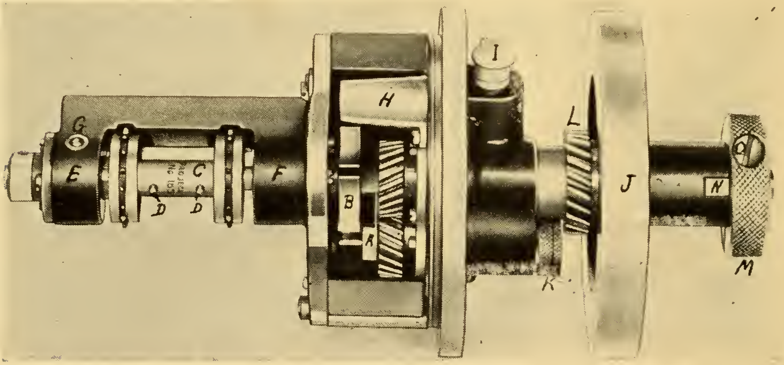


FIGURE 63.

Remembering that cam D rotates continuously in the direction indicated by the arrow, it is evident that presently pin D will engage with one of the slots in star B, and in that instant surfaces E and C will be out of contact and star B free to rotate under the control of pin D. Study the diagram and you will see how it works.

(37) As pin D enters the star slot it moves the star around. The movement is very rapid, but nevertheless by relation the star and its intermittent sprocket (mounted on its shaft) is started slowly and the speed gradually increased to maximum, which is about two or three times the normal 90 feet-per-minute movement of the continuously running film. The star and intermittent sprocket then slows gradually to a full stop, whereupon surfaces E and C re-engage, locking part B im-

movably. The picture is projected and the cycle of action is repeated.

Constructional Details

All reputable manufacturers use only the very finest materials in constructing their intermittent movements. The shape and diameters of the sprockets and the dimensions and spacing of the sprocket teeth are all measured in 10/1,000 of an inch. (38) Any sprockets, stars or cams failing to come within two 10/1,000 of an inch of the correct measurements are rejected.

All intermittent parts are finished by a very high speed, precisely accurate grinding processes. (39) In modern intermittent movements the cam and star are always hardened, but the intermittent sprockets sometimes are not because it was discovered that hardening causes undercutting in the form of a notch in the metal at the base of the sprocket teeth. Teeth not hardened wear off smoothly.

(40) Faulty functioning of the intermittent movement will be magnified on the screen, in the form of an up-and-down movement, as many times as 0.600 is contained in the height, in inches, of the screen image, provided the trouble is due to faulty rotation of the intermittent sprocket. Any lateral (sidewise) movement of the intermittent sprocket will be magnified on the screen as many times as 0.825 is contained in the width, in inches, of the screen image.

Intermittent Lubrication

(41) Considering the foregoing it is obvious that such movements must be lubricated with carefully selected oil. Many theatre managers refuse to buy high grade oil, and then wonder why intermittent movements cost so much for repairs and replacements. It is best that projectionists use no oil in the intermittent movement oil well except that recommended by the manufacturer. Never use light household oils as they will bind up the intermittent movement quickly—and ruin it. The intermittent oil well should be drained and filled with fresh oil following each 100 hours of opera-

tion, but do not flush out the well with kerosene or other liquid. If you do, some portion of it will remain to impair the lubricating properties of the fresh oil. Filling up the oil wells periodically will not do. As oil is used its lubricating qualities gradually wear away and if it is mixed with fresh oil, the fresh oil loses its full strength. Draining at regular intervals is therefore essential.

(42) Dates for draining wells may be determined by dividing 100 by the number of hours the theatre operates per day. The answer is the number of days between drainings and refillings.

Intermittent Sprocket

The intermittent sprocket is part of the intermittent movement. (43) The interval during which the intermittent sprocket is at rest plus the time it is in movement is termed the "speed of intermittent movement." In present day "90 degree movements" the intermittent sprocket is at rest, with the film motionless over the aperture, three times as long as it is in motion.

A quarter segment of a circle is 90 degrees. (A circle is divided into 360 degrees.) Pin D, in Fig 62, is an engagement with the star slot and therefore moves the intermittent sprocket through exactly 90 degrees, but is disengaged for the rest of the circle or (360°-90°) 270 degrees.

Because the intermittent sprocket is in motion one-fourth of the complete intermittent cycle of action, the movement is a "three to one." The film lies over the aperture three times as long as it is in motion, though since the rotating shutter has two blades of equal width, the time of actual projection is reduced, approximately to half that time. In actual practice the period of projection is really a little more than that.

(44) The film is fed down to the aperture by upper sprocket A (Fig. 64) at a regular, unvarying rate of speed, namely, 90 feet per minute, or 18 inches per second. It is taken away by lower sprocket G, at the same rate of speed. Between these two sprockets it is moved intermittently by intermittent sprocket E—its

total speed at this point being exactly equal to that of he film above and below sprockets A and G. (45) The intermittent movement film action is made possible by upper loop D and lower loop H, which function to absorb the stoppage of the film between the steadily moving sprockets A and G. (46) While the film is stationary at

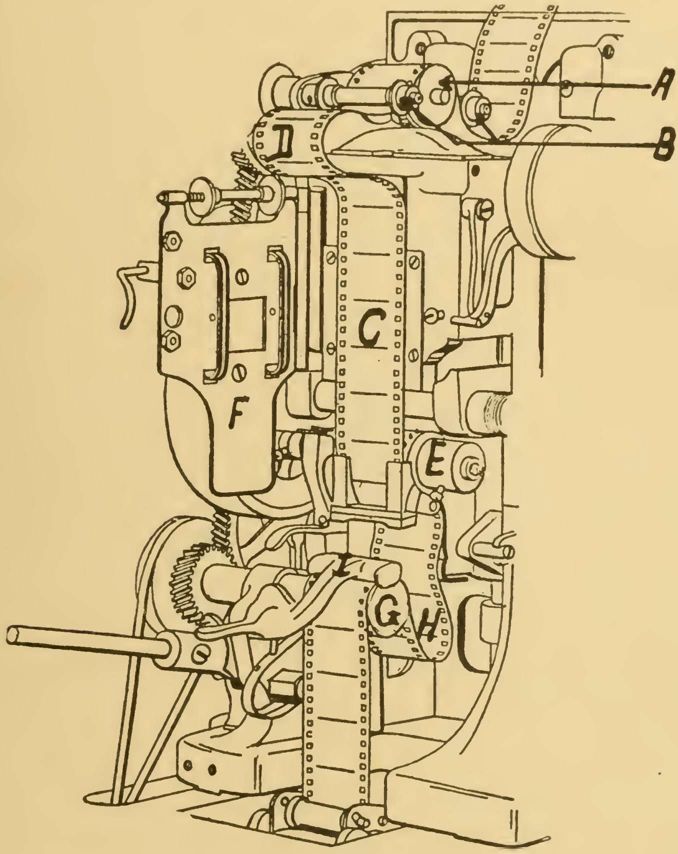


FIGURE 64

aperture C, loop D becomes longer and loop H shorter, and since during each cycle of action by the intermittent sprocket exactly three-quarters of an inch of film is moved down over the aperture, exactly that length of film is fed to upper loop D by sprocket A and taken away from loop H by lower sprocket G. The compensation is equal and the action can continue indefinitely.

Inspect Sprocket Teeth

(47) The constant friction of film against metal wears the metal away. Worn intermittent sprocket teeth not only produce an unsteady picture but tear the film sprocket holes. Therefore the intermittent sprockets should be examined after each fifty hours of operation. Use a magnifying glass to discover the flaws that frequently cannot be seen by the naked eye. If there is any visible undercutting in the form of a small notch at the base of the working side of the teeth, the sprocket should be replaced at once. If no notch shows but the teeth are appreciably reduced in width at their base, they are equally useless and harmful.

Lost Motion in Intermittent Sprocket

(48) Adjustment between cam A and star B (Fig. 62 and 63) must be accurate to permit no perceptible movement of the intermittent sprocket. Test it by rocking it back and forth with your finger while the movement is on the lock. At the same time the adjustment must not be too close or it will have a tendency to bind when the projector mechanism flywheel is turned. (49) The adjustment is correct when the flywheel rotates freely and there is no lost rotary motion in the intermittent sprocket when the movement is on the lock —that is, when the locking ring C is engaged with one of the star quarter-circles E.

The intermittent movement may be adjusted either when the mechanism is hot or cold.

Replacement of Intermittent Sprocket

Few projectionists are equipped, either with tools or experience, to perform this task with the necessary accuracy. Unless an intermittent sprocket is installed on the shaft perfectly, faults will show up on the screen, either as an up-and-down or lateral movement of the whole screen image.

(50) There must be no looseness between the shaft and the sprocket, nor should it fit over-tightly upon the shaft. If it is too loose the sprocket rim will not rotate in a true circle with relation to the shaft. It will wobble and result in a vertical movement of the screen image. If it is too tight the sprocket will be strained—forced out of true form—which may result either in side weave or an up-and-down movement of the screen image or both.

(51) In the event that the projectionist decides to install an intermittent sprocket himself the best procedure is as follows: Remove the intermittent movement from the projector and the sprocket and its shaft from the movement. Remove the taper pins (remember they are taper pins) holding the sprocket to the shaft. Then with the help of a clean piece of cloth grasp the shaft in one hand and the sprocket with the other, and pull it off the shaft with a twisting movement.

Or it can be done another way. Lay the end of the sprocket hub on wooden blocks placed on the jaws of a slightly opened iron vise, place a hardwood block upon the end of the shaft and tap upon it very gently, driving out the shaft. Be very careful not to let the shaft touch the jaws of the vise.

(52) Next clean the shaft thoroughly and lubricate it with a good grade of oil. Insert it in the new sprocket and, using a twisting motion, work the sprocket slowly onto the shaft. If it sticks, remove it, wipe the shaft, re-lubricate and try again. Keep doing this until finally the sprocket slips into correct position.

Put the taper pins in very carefully and drive them in snugly, but not too tightly or you may strain the sprocket hub and force the whole thing out of true line.

In twisting the sprocket onto the shaft, remember that both shaft and sprocket are made with the greatest accuracy, so that it can only be necessary to wear off perhaps the thickness of 1/10,000 of an inch of metal by the twisting motion.

(53) In the event you do not care to purchase the pin ejector, you can make a V block as shown in Fig. 65. If

covered with vaseline and protected from rust it will last a lifetime.

Aperture Tension

(54) When there is too little tension the screen image is unsteady. (55) Too much tension, on the other hand, imposes a great strain upon many parts of the intermittent mechanism, chiefly upon the delicate edges of the sprocket holes of the film, upon the motor that drives the projector, upon the projector gear train and consequently upon the shaft bearings which give the gears their support, and generally upon all working surfaces of the intermittent movement including the edges of the sprocket teeth and the tension shoes and aperture plate film tracks.

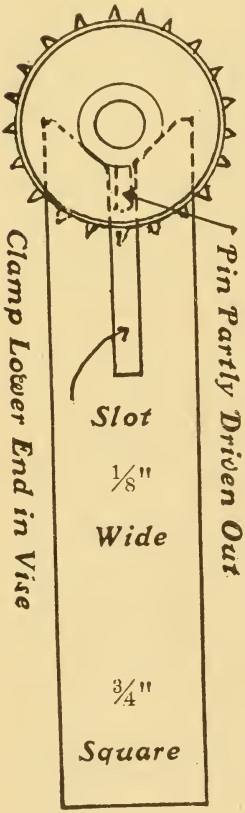


Figure 65

Even under the best of conditions the intermittent mechanism represents a sensitive adjustment of precisely accurate parts working at top speed under strain. Some sections of the intermittent assemblage must start, reach high speed and stop twenty-four times each second for long and continuous periods of time each day. This truly "nerve-wracking" action takes place against the braking effect of the aperture tension.

(56) If the tension applied at the gate is just enough to permit the film to stop perfectly still for a brief interval over the aperture (without unsteadiness or overshooting of the screen image), then the intermittent is accomplishing its work smoothly. But if the aperture tension is excessive, the actuating pin D in Fig. 62 will press against the side of the star slot with sufficient force to overcome the pull of normal tension and this added to the excessive tension at the aperture will, in time, destroy

the delicate adjustment of the whole intermittent mechanism, which moves at the terrific speed of 1,440 times per minute.

(57) Here is a very simple method of obtaining the proper tension: adjust the gate tension so that the screen image just begins to be unsteady or the film begins to overshoot (the screen image moves up slightly) when projection speed reaches 100 feet per minute—and since today all projector motor speed is fixed at 90 feet per minute, disconnect the motor and crank the mechanism by hand. The extra ten feet of speed will allow for any variations of the braking effect on different film. If you do this, you will find the tension correct at the regular projector speed of 90 feet.

(58) Care must be exercised to prevent uneven tension where the tension is provided by two separate tension shoes, each with an independent spring. An ordinary, small postal scale will help to achieve the proper balance. First remove the letter pan. Arrange a block of wood under the two springs, so that each will strike it when pushed down a certain equal distance. Place the letter pan against the center of the shoe and press it down until it just misses contact with the wood. Note the scale reading and repeat the process on the other shoe. You will find this a reasonably accurate method of checking the tension of the two springs.

Flatness of Film Over Aperture

(59) If one conjugate foci point of the projection lens is the film at the projector aperture and the other the screen surface, why must the film lie perfectly flat over the aperture?

One conjugate foci—that is, the optical center of the lens in relation to the film at the aperture—is very short as compared with the other—the optical center of the lens in relation to the screen—hence a very small change in its length will affect the front foci point considerably.

Suppose we now consider the surface of the film at the aperture as thousands of pinpoints, each of which is sending its quota of rays to its corresponding point on the screen—as is actually the fact. If the film lies perfectly flat (we disregard the fact that to make this hold perfectly true the screen must present a spherical surface the center of which would be the optical center of the projection lens) then all these thousands of conjugate foci points would be of exactly equal length, hence all of them would focus equally well.

Suppose the film does not lie flat over the aperture. Instead it buckles in or out about 1/64th of an inch. Such a condition, it is readily seen, makes some rear end conjugate foci points longer than others, and since a difference of 1/64th of an inch in the short end will make quite a lot of difference as to where the front, or long end will focus, it is evident the screen image will not be in sharp focus over its entire area. If the center is focused, the sides will be "out," and vice versa.

(60) Naturally when the surface of the tension shoes and aperture plate tracks become worn, the film will pass the aperture in curved form, not perfectly flat as it should. Parts of the screen image will not be in sharp focus.

Because of the basic importance of perfectly flat aperture plate tracks and tension shoes wearing surfaces, it is recommended that (61) after each 50 hours of projection service (260,000 feet of film) the surface tension shoes or aperture plate tracks (whichever is most convenient) be tested with a steel straight edge. If they do not present a perfectly straight, flat surface, then both tension shoes and aperture plate tracks should be replaced immediately.

(62) When installing new aperture plate tracks, or a new aperture plate, if plate and track form one unit, make very sure that the surface that is to receive them is perfectly clean. A small deposit of dirt, almost invisible, may throw them out of true, perhaps by several thousandths of an inch. When the installation is completed test the surfaces of both tracks with a steel straight-edge.

Why a Shutter is Necessary

(63) The human eye has the ability to retain upon its retina the impression of any light incident thereon for a small fraction of a second after the light itself has vanished. This "persistence of vision" makes motion pictures possible.

Darkness is invisible, except as a contrast to light. (64) The light upon a screen surface is the only thing that is visible to or makes any impression upon the eye. Looking at a screen we see certain shades of light thereon, while at the same time certain portions of the screen surface are more or less invisible. It is the pattern formed by various shades of light that forms the screen image.

(65) If we were to remove the rotating shutter and project a reel of film, we would see very little picture. In its stead would be a series of more or less jumbled streaks of light. As the film moves across the aperture the transparent areas (light spots) move with it, and, with the shutter removed, the eye sees them move in the form of streaks of light. Due to persistence of vision, the bright spots in the picture will be impressed upon the eye while the film is at rest, and the eye will also see them while the film is in motion over the aperture, very largely obliterating the shadings that form the picture on the screen.

(66) It is obviously necessary to cut off all light from the screen while the film is in motion over the aperture,* and that is exactly what the master blade of the shutter does. Each time the intermittent sprocket comes to rest, the master blade moves away from in front, "opens the lens," permitting light to pass through.

We have cut the light off the screen while the film is in motion over the aperture, but to the eyes in the audience the fact is not apparent. Why this is so we shall presently explain.

*It has been found that, without affecting the screen image, the lens may be about one-third open when the intermittent sprocket starts to move, and may be about the same distance open when the sprocket finally comes to rest, which of course adds to the total of screen illumination.

Why the Second Blade

(67) As has been shown, it is essential that the light be cut off from the screen while the film is in motion over the aperture. That fact explains the master blade, but what is the purpose of the cut-off blade?

The science of optics has not yet given a completely satisfactory answer. The facts are that the periods of darkness must not be too long and the periods of light and darkness must be correct in length and of approximately equal duration in time. If we used but one shutter blade (the master blade) we would have a terrific flicker. If—when projecting 90 feet of film per minute—we add a second blade (called the cut-off blade) of approximately equal width with the master blade, and located at the opposite diameter from the master blade, so that periods of light and darkness are equally spaced and of approximately equal duration (in practice the light holds just a little longer than the dark intervals), all visible flicker will disappear. Not only that, but the impression of light from one period of illumination will carry over (persistence of vision) through each dark period, so that we shall have the *illusion* of constant screen illumination. (68) Moreover, the difference in position of the various moving objects in the picture will be so slight that they will blend together into another illusion, namely, that of continuous motion. Put into a different phraseology, each picture "fades" into the next (which as a matter of fact is a precisely correct statement), and thus the slight differences in position of moving objects is merged into continuous motion.

Setting the Shutter

(69) Setting the shutter is a very simple operation, once we remember that the function of the master blade is to cut off all light (cover the light beam) while the film is in motion over the aperture. First loosen the shutter so that it may be rotated on its shaft while the flywheel of the mechanism is held stationary. Then, by means of the flywheel, move the mechanism in its normal direction until the intermittent sprocket is exactly on

the point of starting to move. Be sure to get it exactly at the point of starting. Next, rotate the shutter on its shaft in its normal direction, meanwhile holding the flywheel motionless, until a point is reached where the forward edge of the master blade is approximately two-third of the way across the projection lens. Tighten the shutter on its shaft and the job is done, though some slight adjustments may be needed after trial.

Before starting to set the shutter of a projector equipped with a shutter self-setter, be sure to place this device in the center of its movement.

Rotating Shutter and Intermittent Speed

(70) Knowing that the shutter must have two blades, and that the flashes of light and darkness on the screen must be of almost equal duration (there may be some variation, but too much will result in flicker), it is evident that the narrower the shutter blades are the greater is the amount of light that will pass through to the screen. What then determines the necessary width of the master blade, and as a consequence the width of the cut-off blade?

You will recall that the master blade must be wide enough to "close the lens" while the film is in motion over the aperture, although, as indicated, a slight opening is permissible at the start and stop of the intermittent sprocket. It is evident, then, that the shorter the time the intermittent movement is in motion the shorter the time the lens must be covered. (71) Put another way, the faster the speed of the intermittent movement and, therefore, the intermittent sprocket action, the less time must be given to covering the lens and therefore more light will pass through to the screen.

The projectionist can do nothing to alter the intermittent speed. Most movements are now what are known as "three-to-one." One complete rotation of the cam carrying actuating pin D, Fig. 62, is one complete cycle of action. Divide that action into four equal parts: the intermittent movement star, and therefore the intermittent sprocket mounted on its shaft, is in action moving the film down through one of those parts, and standing still through three of them. (72) "Three to one" has been shown to be as fast a speed as the film sprocket hole edges and intermittent movement parts will stand. If it were faster, the movement would wear out too rapidly and the film sprocket hole edges tear up and break apart. For best results the film lies over the aperture three times as long as the film is in motion past the aperture.

Old and New in Shutters

(73) The old practice was to locate the rotating shutter on the screen side of the projection lens, having no effect whatever upon the heat which was concentrated continuously upon both the film and the projector mechanism cooling plate. Where a high amperage was used (or a reflector type lamp with no condenser to absorb and dissipate a portion of the heat) the film and the mechanism were both subjected to very high temperatures, as a consequence of which the film buckled, and sometimes the projector mechanism frame was warped out of shape.

Later this type of shutter was replaced by the superior rear shutter now in very general use. It is located between the light source and the film, and since it cuts off a little more than 50 percent of the light (74), it cuts off an equal amount of heat from both the film and the mechanism. This shutter is available in two radically different types, each of which will be considered separately

The Disc Type Rear Shutter

This type is, in effect, the old in-front-of-the-lens shutter somewhat enlarged in diameter and relocated just back of the projector aperture, (75) approximately five inches away. At this distance it must, with some types of beam converging element (lens or mirror), cut a light beam of considerable diameter, since the beam diameter in any direction is increased as the distance*

*The distance of the shutter from the aperture differs on different makes of projectors, though not very much. These quoted here are taken from the Super Simplex.

from the aperture is increased. (76) In the Super Simplex, the center of the light beam is 3 15/16 inches from the center of the shutter shaft; hence the edges of the blades must travel at high speed at that point, cutting through the beam diameter very quickly.

In all circumstances the master blade of the shutter must be wide enough to shut all light from the screen while the film is in motion over the aperture, except for the slight leeway permissible at the start and stop as

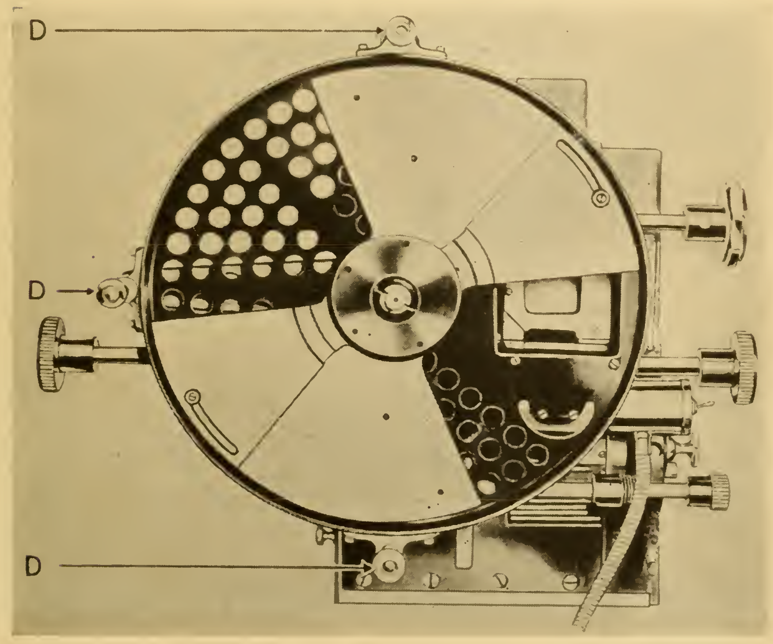


FIG. 66.—Simplex disc type rear shutter.

previously indicated. In other words, the width of the master blade depends to some extent upon the speed of the intermittent movement. Apparently the speed at which the edges of the master blade move decides, in a measure, the width of the master blade and the other blades. (77) The variation is small, but since the shutter goes into action 96 times each second (two blades, each with two edges), it is an item of importance.

(78) All modern shutters have two blades of equal width—hence either may be used as a master blade.

All rear shutters cause movement of the air around them. (79) In the Simplex disc type shutter, one side of each blade has a vane fixed at an angle to the line of rotation. This vane is approximately half an inch wide by about four inches long. When the blade is rotated at high speed the vane forces a strong current of air outward (toward the lamphouse), dispersing a considerable portion of the heat from the light source; the vane also draws air into and around the mechanism and helps to keep both the mechanism and the film at low temperature, without causing any great amount of dust to circulate from deposits at the aperture. All shutter blades are adjustable for width.

The Horizontal, Cylindrical Type Shutter

(80) This type of shutter is radically different in design and operation from the disc type. Essentially it is a hollow cylinder of metal, rotating in an enclosed housing.

(81) The Motiograph horizontal shutter is a light aluminum casting rotating on ball bearings and enclosed in a small metal housing. The shutter is positioned transversely (horizontally). In its cylindric surface are two openings through which the light beam passes; the rest of the cylinder serves exactly the same purpose as the blades of the disc shutter. Its cylindrical diameter is 3.25 inches. Its axis is 4 inches from the projector aperture.

(82) What is true of the speed and width of the disc type master blade edges does not apply to this shutter, and for two reasons: it is located closer to the projector aperture and consequently has a smaller beam diameter to cut; the shutter is positioned horizontally, or transversely of the beam, the light passing through its center or cylinder so that when one blade is cutting down through the beam the other is cutting upward, the two meeting at the beam center. Only half the time is required to cut off the light that would be necessary

were only one blade in active operation. (83) Of the two blades each acts as a master and cut-off blade.

(84) The Motiograph horizontal rear shutter is shaped at each end of the cylinder to act like a fan or air propeller. From each end air currents are directed toward the center of the cylinder. Each of the two blades of the cylinder has a transverse vane, which, in combination with the propeller ends, sets up air currents and draws them in through the opening of the shutter housing at the cooling plate, (85) and forces them out

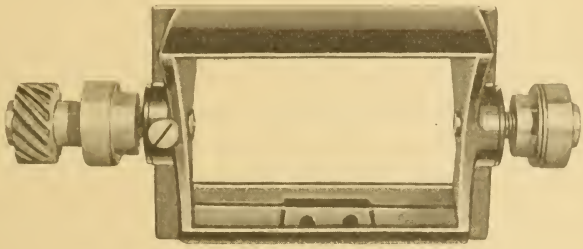


Fig. 67.—Motiograph Horizontal type rear shutter.

of the shutter housing toward the lamphouse. This draws air over the metal of the projector mechanism around the film gate, keeping it and the film at relatively low temperature and preventing deposits of dust.

The cylinder shutter, like the disc type, may be adjusted manually and may be partially adjusted while the projector is in motion.

Regulating the Front Shutter

Front shutters have been abandoned almost entirely for theatre projectors. Their use subjects both the film and projector mechanism to excessively high temperature and they should be replaced by the newer type shutter located between the light source and the aperture. Some are still used, however, therefore the following information concerning them is of value.

(86) Were a screen held in front of a projection lens at a distance corresponding to the focal length of the lens, an image of the converging condenser lens or

mirror would appear thereon. The point in distance at which it appears is known as the "point of aerial image." The image of the converger may be made visible by means of a screen of dark cardboard.

Since the divergence of the light beam immediately in front of the projection lens differs for different e. f. projection lenses, (87) it is quite important that the shutter be located, as nearly as possible, at the point of aerial image. In some cases this point may be too far out to be reached because the shaft of the shutter is too short.

The exact location of the point of aerial image may be ascertained by projecting light to the screen and slowly passing an opaque object downward through the light beam at different distances from the lens, until a point is found where a shadow starts from both top and bottom of the screen at the same time, meeting in its center. (88) This is the point of aerial image, and here the master blade of the shutter may be narrower than at any other point because in passing through the beam the blade produces a dissolving effect, as is shown by the shadow at the top and bottom when the opaque object cuts across the beam. (89) If, because of the short shaft, the shutter cannot be located at the point of aerial image, the projectionist should put it where, in his judgment, the master blade will operate efficiently at minimum width, remembering that the narrower the blade the more light will pass through to the screen. Merely to locate the shutter at the point of aerial image without reducing the width of the blade is lost motion and energy.

(90) The projectionist may test for the width of his shutter blade in the following manner: remove the shutter from the shaft and the blade from its hub. Lay the blade on a piece of thin, stiff cardboard about 12 inches square and with a pencil trace the outline of the blade. Cut the cardboard pattern out and clamp it into the shutter hub, just as if it were the metal blade, and put the shutter back on the projector in its proper place. Don't bother to connect the outer edges of the paper

blades; if the cardboard is strong it will run perfectly for several days without such connection.

Having set the cardboard blade properly, project a black and white title upon the screen and continue to trim off small but equal amounts from each edge of the master blade, after each trial projection, until a faint travel ghost begins to creep up and down upon the screen. Now the blade is just a bit too narrow on both sides. Remove it and trim the metal master blade to almost the same proportions, but a little wider to kill all traces of the travel ghost. Additional width, to be determined by the projectionist, must be provided or travel ghost will appear as soon as the mechanism gears and bearings begin to wear. (91) Trim the other blade to the same width as the master blade, always taking off an equal amount from each side. The shutter is now ready for efficient operation allowing maximum light on the screen.

Trimming the Rear Shutter Blades

Since the rear shutter is located a fixed, unchangeable distance from the projector aperture, (92) the projectionist is only concerned with the width of the blade and the air movement it creates. He need only ascertain whether or not the shutter is keeping too much light from the screen. He can do this easily if the shutter is an adjustable one, as most disc-type shutter blades are: reduce the blade until travel ghost appears, and then increase the width slightly until it again disappears. (93) If the shutter has non-adjustable blades it is possible to make a test along the lines suggested for the front shutter, only an experimental blade of sheet metal, not of paper, must be employed for trimming. Because of the extremely hot light beam paper would be dangerous. This test can be made with the disc type shutter only.

(94) Since some theatres use a wide-diameter, close-up converging element, while others use a small diameter, far-away element, there is a decided difference in the beam depth to be cut by the shutter blades. (95)

The difference may be observed by tracing on paper the outline of the two types and then measuring the depth of the effective beam at the point where the shutter is located. Shutter blades should be variously trimmed to cut the varying beam depths most effectively.

Effective Beam

(96) All light not falling upon the aperture opening is of no importance. The rear shutter master blade does not begin to cut light until its edge passes a straight line drawn from the top of the converging element to the top of the aperture opening—or from the bottom of the aperture opening to the bottom of the converging element provided the shutter runs in the opposite direction and starts cutting from below.

We have therefore coined the term "effective beam," this being the beam of light incident in whole upon the projector aperture. It may be defined as a cone of light bounded by straight lines drawn from the outer, free, diameter of the converging element (mirror or lens) to corresponding points upon the projector aperture opening.

Projector manufacturers hold this definition to be correct, but declare that the effective beam is bounded by straight lines reaching from the projector aperture opening to a rectangle on the face of the converging element, the same shape as the projector aperture, but so large that each of its corners would touch the converger's free diameter edge.

This statement is incorrect when we discover that in some measure a round beam of light can be put through a rectangular opening. This may be proven by painting a converger (mirror or lens) with opaque water color and making a pin hole at its free diameter edge. Upon trial it will be found that a thin cone of light will go forward, some portion of which will always fall upon the aperture opening. It will be found by making other pin holes nearer the center of the converger that more of the spot light made by the cone will reach the aperture opening, until finally, near the center, it is likely the entire cone will enter the aperture opening and therefore become available to the projection lens. This pin-hole experiment should be very interesting to projectionists.

The action of each cone of light may be investigated by blowing smoke into it. Tobacco smoke will serve, all film first having been put carefully away. A thin metal plate with drilled pin holes may be used, provided the experiment is made with a plano-face converging lens and the plate lies snugly against the lens.

(97) Projectionists may lay out the effective beam as per Fig. 68 in which line AB is on the optical axis and just long enough to reach from aperture B to plane of converger at A, broken lines representing the outline of the converger light beam as a whole. CC is the cooling plate.

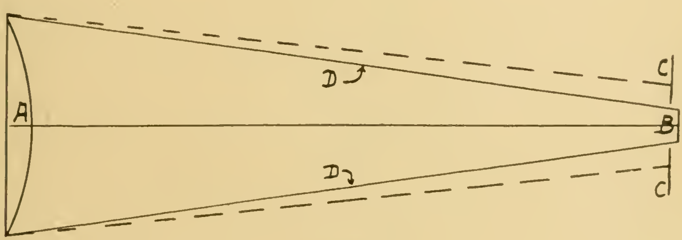


FIGURE 68

All light outside of lines DD is wasted light and of no value when considering shutter action. The light between lines DD is the only light that is effective, hence it constitutes the "effective beam."

THE GEAR TRAIN

(98) The gear train not only drives the entire motion picture projector mechanism, but also, as shown in Fig. 63, locks the intermittent movement cam, A, to the rotating shutter so that they rotate in exact synchronism—the shutter making one complete revolution to each complete cycle of action of the intermittent sprocket. At 90 feet per minute projection speed the intermittent sprocket acts 24 times per second. Through

the gear train the master blade of the shutter is made to cut off all light from the screen and to turn it on again at precisely the right instant of time.

(99) There is lost motion even in a new gear train —about 3/16 of an inch free movement of the intermittent flywheel while the shutter is held stationary. Projectionists should watch this carefully. New or repaired mechanisms that have a greater ratio of lost motion should be rejected.

(100) As parts of the mechanism wear, lost motion will increase. It should never be permitted to be more than 5/16 of an inch. If the ratio is higher it is evidence that the mechanism needs a general overhauling.

The gear train may not be altogether responsible for lost motion. Often it is due to worn bearings and other factors in the intermittent movement.

(101) To measure lost motion affix a prick-punch mark to some part of the mechanism frame as close as possible to the rim of the flywheel of the intermittent movement and a similar one near to the inner edge of the flywheel rim. By fixing one point of a calliper, or an ordinary carpenter's compass, in the mark on the frame with the other point at the mark on the flywheel rim, the distance the flywheel can be rotated may be accurately measured. Be very sure to hold the shutter perfectly still while testing the flywheel rotation.

The foregoing test was developed by projection manufacturers especially for this edition of the BLUEBOOK and has become the official, standard method of checking the gear train for lost motion.

Gear Lubrication

Projectionists differ as to what constitutes the best form of gear lubrication. (102) Manufacturers recommend a fairly ample lubricant of a good grade of medium weight oil. A good quality lubricant keeps up a slow but constant washing of the gear surfaces and works out much more rapidly than heavy oil or grease, which collects dust and grit from the air.

Lubrication of Bearings

(103) One drop of oil, or two at most, is ample lubrication for any projector mechanism bearing. The mechanism will throw off more than that, making a dirty mess and spotting the film. Use a medium-sized oil can having a fairly long spout with a small opening. Invariably, except in the hands of a very careful man, a big oil can with a generous spout opening will result in over-oiling.

Sprocket Idlers

(104) The function of holding the film close to the face of the various sprockets is performed by sprocket idlers, consisting either of one or two rollers per sprocket or a thin steel shoe. In all modern projectors one or two rollers are used for all sprockets except the intermittent. Here Simplex uses a thin steel shoe.

Whether it is a shoe, a roller or rollers (some projectors have two rollers to each sprocket and some only one), the rule is (105) that the distance from the face of the roller or shoe to the face of the sprocket must be approximately one and one-half times the thickness of the film. (106) To arrive at this lay two thicknesses of film on the sprocket and adjust the roller bracket or the shoe firmly against the film with the adjustment screw in firm contact with the stop it rests upon.

(107) If the shoe or roller is too close to the sprocket face it will pinch the film. It will then start a tendency to side-weave, causing the sprocket teeth to climb out of the sprocket holes. If the shoe or roller is too far away the same condition may be brought about, though for a different reason, resulting in the loss of one of the loops. Proper adjustment of sprocket idlers is important.

(108) It is also important that each end of the sprocket idler is exactly the same distance from the sprocket face, since any variation will cause the film to pull sidewise away from and off the sprocket teeth. (109) If the idler is a roller it must be kept well lubricated with a thin oil, else it will stick and quickly wear flat on one side. In that case it must be replaced imme-

diately. Do not use heavy oil. The much advertised household oils are excellent for this purpose; or the oil you use for the projector, mixed half and half with kerosene, will do very well. All idler rollers, including those of the fire trap, should be inspected each day before the first run to make sure they are rotating freely. Sprocket idler rollers should be given one drop of oil each day, wiping all surplus oil carefully away.

Upper Magazine Tension

Every first class projector is equipped with some sort of device to supply tension to the reel in the upper magazine (110) to hold it in retard. This brakes the momentum of the reel, which otherwise would continue to run rapidly after the projector is stopped. Should that occur, when the projector is again started and the slack is taken up, the reel will start with a hard jerk, which is likely to pull the film apart. The necessary tension may be determined by experiment outside of show hours, starting and stopping the projector several times, meanwhile adjusting the tension until the braking effect is sufficient.

Lower Magazine Tension

The reel in the lower magazine must take up (rewind) 90 feet of film per minute. At the beginning, when the film roll is small, the reel rotates at high speed, gradually slowing down as the diameter of the roll increases. (111) To provide for this continuous change in speed, slippage is provided for between the driving pulley and take-up reel spindle. In its simplest form this slippage consists of two metal discs, several inches in diameter, between which is a plate of fibre friction material. These two discs are held together by spring pressure sufficient to provide friction to drive the take-up spindle, at the same time allowing slippage to compensate for the continuous change in speed. (112) The spring pressure should be as low as is necessary to keep a slow moving film-laden reel in rotation until the end of the run. Adjust the tension so that when the reel is full its rotation may be stopped by a slight touch of the finger at the rim of the reel. (113) Too much tension is bad. It is hard on the film sprocket holes; it wears the lower or "hold back" sprocket teeth unnecessarily. There must be just enough to drive the reel without danger of it stopping.

Magazine Rollers and Fire Trap

The rollers are presumed to make it impossible for fire to get through the fire trap. They are spaced exactly right by the manufacturer, the maximum distance being fixed by Underwriter's rules. (114) Where old films are usually used the fire traps should be examined once each day. When using new films, upon which the emulsion is soft, the rollers should be examined after the projection of each reel to make certain no deposit of emulsion has accumulated. (115) The fire trap rollers are made of material that requires no lubrication, but if lubrication seems necessary, use only a light oil sparingly.

Path of Film Through Projector Mechanism

(116) Projectionists should make a thorough daily inspection of the entire path of the film (commonly called the "film track") through the projector mechanism between and including the upper and lower magazine fire traps. (117) If first-run films are used inspections must be made after each run to make sure no deposit of the soft emulsion has accumulated at any point. A vast amount of damage, in the form of scratches in the emulsion, is inflicted upon film every day by these deposits of emulsion on metal.

In inspecting the film track, run your fingertips over each inch of flat space which the emulsion side of the film contacts in its course from upper to lower magazine; also examine the fire traps and sprocket idler rollers for the same troublesome emulsion deposits.

(118) The aperture plate tracks or surfaces of the tension shoes (whichever the emulsion side of the film contacts) should also be carefully inspected before each

reel is threaded in, unless only old, well-seasoned films are used.

(119) The film must pass through the projector and sound mechanism in a perfectly straight line. (120) It is guided past the aperture of both the projector mechanism and sound head by lateral guides, which should never be disturbed except to be replaced. (121) Assuming these guides to be rightly placed, the correctness of the path of the film elsewhere may be judged by examining the loops (see Fig. 53), which should set perfectly "square." If either or both of the loops are at all distorted (crooked) it is—unless caused by the presence of a poor film splice in the loop—evidence that something requires immediate attention.

If it becomes necessary to remove and replace a lateral guide follow the manufacturer's instruction book, or if this is unavailable secure detailed instructions by addressing the projector manufacturer. Correct placement of the lateral guides is necessary to good projection.

The Automatic Fire Shutter

Projectors are all equipped with an automatic fire shutter (122) consisting of a mechanically controlled sheet of metal that drops down, automatically, between the cooling plate and aperture, cutting off all light from the film and the screen the instant projection speed is reduced below the safe limit which is the moment the film is in danger of ignition because of the slowness of its passage through the intense heat of the spot.

(123) The mechanical operation of the fire shutter varies widely in different makes of projector, but in none of them does it require much attention beyond lubrication. (124) The fire shutter should not rise until projection speed has fallen to at least sixty (60) feet of film per minute. It should drop automatically when projection speed falls below sixty feet of film per minute. (125) Projectionists should check the rising and falling speeds of the shutter at least twice a week to make sure the device is operating properly. Improper action of the

fire shutter is a decidedly dangerous condition, especially in one-man rooms.

Size of Loops

(126) Between the upper and lower loops in the projector mechanism the film moves intermittently exactly three-quarters of an inch each time. Both loops must therefore contain that amount of slack film, and a little more. (127) To arrive at the required loop size, thread in a film and operate the mechanism slowly by means of the flywheel; watch the loop action and gradually diminish the loop length until it has just the amount of slack necessary for smooth operation. Some projectionists prefer to make the loops as large as possible without forcing the film to rub on the upper or lower fire shields.

(128) In closing the subject of the projector mechanism we must stress again the importance of keeping it scrupulously clean. Lubricants should be selected carefully unless the one recommended by the projector manufacturer is used. Do not expect any projector mechanism to give good results unless it is kept in a state of repair and in perfect adjustment, and remember that "repair and adjustment" includes frequent, thorough inspection of the various parts.

THE PROJECTION ROOM

1. Why is the projection room the vital part of the theatre?
2. Upon what does excellence of projection depend?

Good Working Quarters Important, page 247

3. Can projectionists do their best work in badly planned projection rooms?

Location, page 247

4. What is an important point in the location of the projection room?
5. What should be the limits of projection distance?
6. Name the objections to too-short or too-long projection distance?
7. Is it sometimes commercially advisable to sacrifice seating space to avoid a poor projection room location?

Construction Details, page 248

8. Are insurance rates higher if the projection room is faultily planned and constructed?
9. Should exhibitors examine into insurance rates and the effect your projection room planning has upon them?
10. Is the old style projection room effective in either fire or sound proofing?
11. Describe one form of projection room wall construction that is now much used.
12. Name another excellent building material for projection room walls.
13. What is it essential to do in connection with hollow tile walls?
14. What kind of finish on both sides should hollow tile walls have?
15. When should conduits be put in place?

Projection Room Ceiling, page 249

16. Should exhibitors give careful consideration to ceiling construction?
17. What is a satisfactory substitute for a ceiling?

Projection Room Floor, page 250

18. Describe method of building a concrete floor.
19. How thick should the concrete underlay be?
20. Should a cement floor that is to be used without covering or treatment be of high grade cement?
21. Is it good practice to use a raw, uncovered, untreated cement floor?
22. What is the best cement floor covering?
23. What should be done if battleship linoleum or its equivalent is not used?

Dimension of Room, page 250

24. How high should the ceiling be?
25. What should be the length of the projection room?
26. What should be the depth from front or rear wall?

Spacing the Projectors, page 251

27. Name a good rule to follow in spacing projectors.

Lens and Observation Ports, page 251

28. How large a wall opening should be left for lens ports?
29. May openings (ports), other than those used for observation be reduced in area?
30. What is the governing factor in the size of observation ports?
31. Do observation ports less than twelve (12) inches square offer any elements of safety?
32. What should the size of observation ports be?

33. What should be the distance from the floor to bottom of observation ports?
34. What should be the color of the wall immediately surrounding observation ports.
35. What should be the size of the effect and stereopticon lens ports?
36. What governs the size of spot light ports?
37. Should spot ports be covered with glass?
38. Should ports in thick walls be flared outward?

Conduits, page 254

39. Who should be consulted before installing conduits?
40. Should conduit runs and outlets be indicated on the building plans?

Lighting the Projection Room, page 255

41. Has projection room lighting been handled intelligently?
42. What will reduce ability of projectionist to see screen image clearly?
43. How may the effect of improper lighting be tested?
44. How is the projection room properly illuminated?

Trouble Lamps, page 256

45. Should every projection room be equipped with at least one trouble lamp?
46. What kind of a trouble lamp is best and how much cord should it have?
47. How is its reel controlled?

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48. Should rheostats be located in the projection room?
49. Is a separate rheostat room conducive to safety, health and comfort?

MOTOR GENERATOR ROOM, PAGE 257

50. Where should the motor generator sets be located?
51. Should the motor generator room be sound proofed?
52. Is it permissible to locate the batteries in the motor generator rooms?

BATTERY ROOM, PAGE 257

53. Where should storage batteries be placed?
54. Are unprotected wood floors proper in a battery room?
55. Are storage batteries adversely affected by extremes in temperature?
56. What is the real value of projection room ventilation?
57. From where must air for ventilation be drawn in?
58. Where is it best to place fresh air inlets and the outlet?
59. With what should inlet openings be covered?
60. What about the size of inlet openings? How should the amount of air be controlled?
61. Is it safest and best to have an outlet of ample area?
62. What is likely to happen if a film fire occurs and the outlet is not of sufficient dimensions?
63. Is forced draft ventilation effective for ordinary purposes?
64. Describe the method of operating forced draft ventilation consistent with the health and comfort of patrons and employees.
65. Describe the requirements of a separate system for removal of smoke and gas in the event of a fire.
66. Can a fan be installed to do double duty for ordinary ventilation and for fire emergencies?
67. How large must a fan be to remove smoke and gas?
68. What is the plan for smoke removal illustrated in Fig. 71?
69. Must the outlet duct for such a system as shown in Fig. 71 be insulated from inflammable material?
70. Why is it bad practice to install the motor in the outlet air duct?
71. What is the chief point in the plan shown in Fig. 71?
72. What kind of paint should be used for projection rooms?
73. What should the colors be?
74. What should be the color around observation ports?
75. In what color should auxiliary rooms be painted?

PORT FIRE SHUTTERS, PAGE 262

76. Of what material should port fire shutters be made?
77. What danger sign first excites an audience?
78. What is the real purpose of port fire shutters?
79. How are shutter grooves made?
80. What should be placed in the bottom groove and why?
81. Can ready-made metal port casings be obtained?
82. What is essential to quick action of the port fire shutters?
83. Why are metallic fuses unreliable for quick action?
84. Must all sound be confined to the projection room?

GLASS IN PORTS, PAGE 263

85. Is optical glass for port coverings practical?
86. Why is it necessary to set observation port glass covers at an angle?
87. How should port cover glass be mounted?

LENS PORTS, PAGE 264

88. Should lens ports be covered with glass?
89. Why should the lens ports be kept open if possible?

THE PROJECTION ROOM ENTRANCE, PAGE 265

90. What should the door dimensions be?
91. Why should there be two doors, with a space between?
92. What kind of door should be used?
93. What, on the whole, constitutes a good projection room?

CHAPTER IX.

THE PROJECTION ROOM

(1) The projection room is the very heart of the theatre. It is the working place of men who are called upon to recreate the performance of great artists, both in pictures and in sound. (2) Whether the recreation is good or bad depends to some degree upon the appointments and general conveniences of the projection room itself. (3) Men engaged at tasks that require intelligence and skill cannot be expected to work efficiently in quarters that are badly ventilated, cramped or devoid of simple necessities.

Location

(4) In locating the projection room avoid projection angles, if possible, to eliminate distortion on the screen. The maximum angle approved by the Society of Motion Picture Engineers is 15 degrees. Laterally (sidewise) the room should be located so that where there are two projectors each projector will be located equidistant from a line at right angles with the surface of the screen at its center. Where there are three projectors the lens of the center projector should be on this line.

(5) The projection room should not be too close to the screen or it will require the use of a projection lens of less than 4 inches EF; nor should it be too distant, or it will require the use of a lens exceeding 7 inches EF.

(6) The use of a too-short focal length projection lens makes it impossible to secure sharp definition (focus) all over the screen, a condition that induces eyestrain. The use of a projection lens of more than seven inches EF may mean that not all of the light beam will enter the lens, resulting in loss of light and uneven

illumination of the screen. This condition can be sometimes overcome by using an expensive wide-diameter lens.

Sacrifice Seats

(7) In some cases side and front seats may have to be sacrificed to avoid a very steep projection angle. The use of a too-long or too-short EF projection lens may also be avoided by the elimination of a few objectionable seats. The better screen image obtained by the correct location of the projection room is one of the important factors that keeps patrons continuously satisfied. Nothing is so ruinous to the success of a theatre as distorted or badly illuminated projection.

Construction Details

(8) Too little attention given to the proper fireproofing of projection room walls, doors or ports during construction often means unnecessarily high insurance rates. (9) Careful planning to meet all local and national fire regulations means a great saving in insurance rates.

Sound and Fireproofing

These two items are so closely connected that they may be considered under one heading. (10) The old projection room wall of steel, asbestos board, metal lath and plaster gave a measure of fireproofing, but failed altogether to meet the requirements of soundproofing. (11) One modern practice is to construct walls of double-channel studs, fixing a substantial metal lath on each side and coating them with an approved cement plaster not less than three-quarters of an inch thick. This form of construction (provided a high grade portland cement is used) forms two solid walls, between which is dead air space and plenty of room for conduit. Metal brackets to receive any desired shelving or benches may be attached to the studing before the plaster is applied. When this type of wall is employed, the outer plaster surface is heavily coated with a good plaster-finished acoustical material. Such walls are light in weight and do not store heat or cold to any considerable degree.

(12) Hollow tile is light in weight, has excellent fireproofing qualities and fine soundproofing characteristics and does not store heat or cold appreciably. Hollow tile not less than three inches thick forms the best type of projection room wall, provided the front wall has a good underlying foundation and the tile is laid in good cement mortar tempered with lime—to make the mortar work well. (13) A good foundation for the front wall is necessary because the cutting of the ports weakens its strength considerably.

(14) All walls abutting upon the auditorium should be plastered on the inside with cement mortar to a thickness of at least three-fourths of an inch. A three-quarter-inch-thick coating of acoustical plaster should cover the auditorium side. Walls treated thus will be strong enough, despite the port openings. (15) Conduit should be built into the wall.

The Ceiling

(16) Many theatres are paying high insurance rates because of improperly constructed projection room ceilings. (17) All requirements are met if the room walls join a concrete floor above. Otherwise either of the following two suggestions are practical: Use a 4-inch hollow tile supported by suitable T beams, laying the tile in cement mortar in the same manner as the tile walls. First apply a layer of cement mortar three-quarters of an inch thick and over that—for surface covering—lay a coat of acoustical plaster of the same thickness. Or use iron I beams, each not less than three inches deep, with metal lath above and below, laid in plaster. Two-inch beams are used frequently but these are too light for a deep room.

It is wise to consult local authorities before finally deciding upon any form of wall or ceiling construction. Frequently they insist on certain types of material and construction.

The Floor

(18) The best floor is a top dressing of high grade cement and sharp sand (insist upon the high grade cement and "sharp" sand) laid down not less than one inch thick, supported by a substantial thickness of rich concrete of cement, sand and medium-size crushed stone well tamped into place, with all the various projector and other necessary anchor bolts, conduit, etc., embedded therein. (19) The concrete underlay should be of sufficient thickness to be impervious to vibration set up by the machinery. Be guided by the architect on this point, though a six-inch thickness should be quite sufficient.

(20) Unless the floor is to be painted or covered with linoleum or other material, it is imperative that only high grade cement be used for top dressing. Poor quality cement will be scuffed up rapidly into dust, which will settle on the film, causing minute scratches, get into the machinery bearings causing them to wear very fast, get into the sound equipment causing noisy sound. The best cement will do this to some extent, but a poor quality deteriorates quite rapidly.

(21) Under no circumstances is it good practice to use a floor of raw cement in a projection room. (22) The best covering is "battleship linoleum," dark green or brown in color, cemented to the floor. (23) If linoleum is too expensive, cover the floor with two coats of paint. There are acid treatments that do fairly well in preventing dust formation, but paint is more reliable, and linoleum the best.

Dimensions of Room

(24) Under no condition should the ceiling be less than eight feet from the floor in cool climates. It should be twelve feet in warm climates. The higher the ceiling the better.

(25) The length of the room is dependent upon the number of projectors and other equipment it has—such as spots, effect projectors, stereopticons, etc. Starting

with seven feet for a one-projector installation, six feet are necessary for each additional projector, spot lamp, effect projector or dissolver and a reasonable allowance should be made for additional equipment in the future.

(26) Depth, from front to back wall, should not be less than ten feet where no sound or other apparatus is to be installed along the rear wall. This provides approximately three feet of clear space back of the projectors, assuming them to be set as close as practicable to the front wall. Where equipment is to be installed against the back wall, the depth of the equipment plus any space required at its rear must be added to the regulation depth of ten feet.

Spacing the Projectors

(27) Since projection distance dictates the angle of the optical axis of each projector to the screen surface, the following is a safe rule to follow: if the projection distance is less than 75 feet the distance of the lens center of one projector to the lens center of the second should not exceed four feet. If the projection distance exceeds 75 feet but does not exceed 125 feet, the spacing should be increased to four and one-half feet. If the projection distance exceeds 125 feet, the spacing then should be increased to five feet, all distances measured from lens center to lens center.

Lens and Observation Ports

(28) The projector lens port wall openings should be at least 12 inches high by 10 inches wide. The area of these wall openings should be reduced later to just a little more than is necessary to accommodate the light beam. This reduction should be made after the projectors are finally anchored in place and the light properly centered upon the screen.

In Fig. 69 we see a lens port approximately reduced to the area of the light beam making the use of glass over lens ports unnecessary.

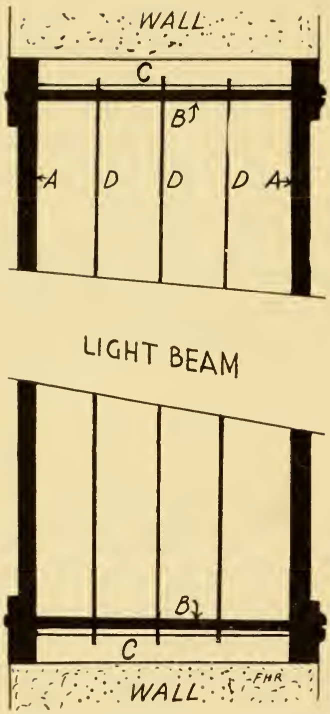

FIGURE 69*

Parts AA are two pieces of fairly stiff, fireproof, sound absorbing material from ⅜ to ½ inch thick, cut to fit snugly but not too tightly into the wall opening at either side of the wall. The surfaces of these plates, on the projection room side at least, should be inset just enough so that iron holding straps will be flush with the face of the wall, thus avoiding interference with the port fire shutter. The holding straps are merely to reinforce parts AA and keep them from warping. A second set of straps may be run up and down if it is thought necessary. Parts AA are secured to the straps by means of rivets.

CC are two pieces of the same material as AA, but no less than one-half inch in thickness. Parts AA are held firmly against the edges of CC by bolts BB, which should be threaded into the inner strap to avoid possible interference of nuts, if used, with fire shutters.

Parts DDD may be set into slots in parts CC which may be saw kerfs, or slots may be made by affixing strips of the material from which parts DDD are made to plates CC, separated to form the slots.

Fig. 69 shows the construction plainly. First, build the entire device at the bench so that it will fit into the wall opening snugly and may be easily pulled out again. When it is finished, install it in position in the wall open-

*This construction is covered by patent, but its use is advised, even though a fee is demanded.

ing and, with the projector anchored permanently in its place and the light properly centered on the screen (use the magniscope lens if one is provided), project the light beam upon part A nearest the lens. With a pencil trace the beam outline on the part, remove the whole device to the bench, take out Part A, cut a hole therein just a little larger than the actual beam, reassemble, replace in the wall opening and do the same thing with every one of the obstructing sheets of material.

When you have finished you will have a port just a trifle bigger than the light beam, with a sound baffle that should make a glass cover, except possibly in very thin walls, unnecessary. Cement around the edges, both inside and out, with half good, clean sand and half cement or plaster of paris.

Three baffle plates should be sufficient, but in case of very thick walls four might be used to more advantage.

(29) Lens ports and openings other than observation ports should be no larger than is actually necessary but (30) observation ports should be large enough to afford a clear view of the screen from any normal working position beside the projector.

(31) Authorities who compel reduction of observation ports to less than twelve inches square gain nothing in added safety, but do reduce the efficiency of the projection crew. They forget that ports are now invariably glass covered and a fire shutter will drop and cover a twelve-inch opening just as quickly as it will cover one of larger dimensions.

(32) Observation ports should be fourteen inches high by twelve inches wide, covered with glass. (33) The bottom of these observation ports should be so located that a straight line from a point opposite the light source and 60 inches away from the floor to the lower edge of the screen image will just miss the port bottom. This makes certain a full view of the screen image from working position regardless of the projection angle. (34) the wall surrounding each port should be painted in a non-gloss black color for a foot and a half in all directions.

Other Ports

(35) Wall openings for effect and dissolving stereopticons should be stepped down until they are no larger than is necessary. It is best to start with ports of ample dimenions. After the projectors are permanently located and anchored down, project the light beam upon the openings, first shutting them off with a fireproof, sound absorbing material. The dimensions of the beams can then be marked, the piece removed and an opening cut in it the size of the light beam. The final openings may then be covered with optical glass if desired.

(36) The width and height of ports for spotlights will depend entirely upon how close the lens is to the wall and through how wide an angle it is necessary to swing the light beam. (37) Some theatres do not close spot ports with glass, opening the fire shutter only when the spot is in actual use, and at this time no conversation or other unnecessary noise should be permitted. In some cases local authorities demand that spot ports be covered with glass.

Ports Flared

(38) If the front wall is more than eight inches thick it is advisable to flare (slope) the bottom of all ports downward, at least to the angle of the axis of projection, provided it exceeds five degrees. If the wall is twelve or more inches thick, both bottom and sides of ports should be flared outward. This applies to all port openings.

Conduits

(39) Before installing sound equipment conduit the equipment manufacturer should be consulted and his advice followed. Unless this is done, very serious inconveniences may be encountered later on. (40) Exact location of all conduit runs and outlets should be indicated on the projection room plans, so that they may be embedded in the walls and floors during construction.

Lighting the Room

(41) Projection room illumination has not, on the whole, been intelligently planned. Here are men engaged in producing certain effects upon an illuminated screen located from 50 to 150 (or more) feet away. They must have the best possible view of the screen, yet this view can be had only through a wall opening of necessarily restricted size.

(42) It is easily understood that if the wall immediately surrounding the port opening is illuminated, or if any light in the projection room shines in the eyes of the projectionist, his view of the screen is hampered. And it is a fact that even today both these bad characteristics exist in projection rooms that are otherwise quite intelligently arranged.

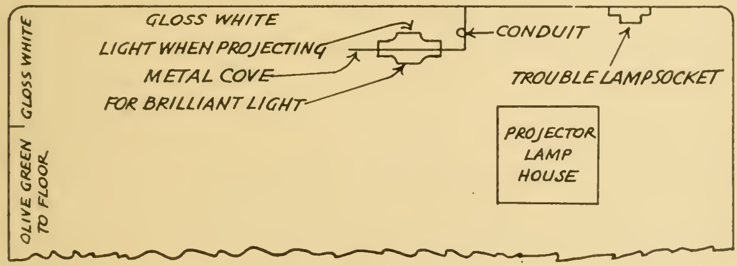

Figure 70

(43) Enter any well illuminated projection room, take your place in working position beside a projector, watch the screen—then suddenly have the room illumination turned off. You will be amazed at the increased clearness with which the picture details on the screen can be discerned.

(44) Following is what we regard as a good plan for projection room illumination. Fig. 70 shows an end view of a sheet metal cove attached to the ceiling, its length extending to within six feet or less of each wall. The cove should be located over the rear end of the projector lamphouses. Its interior, the ceiling from it to the rear wall and a sizable section of the rear wall

down from the ceiling, should all be painted a gloss white color. All other wall surfaces should be a dark olive green or dark brown color, except a strip 18 inches wide, in flat black color, around the observation ports and around the metal surfaces of the port fire shutters.

Enough incandescent lamps should be installed in the cove to provide a reasonable amount of illumination during projection. Fig. 70 shows that the light source lamps are completely concealed from view of the projectionist except when he is near the rear wall. We also see that all light comes in diffused form from the rear of the ceiling and from the top of the rear wall, falling upon the back of the projectionist and not upon his eyes when he is in working position beside the projector. The rear of the room can be well illuminated. The only possible objection to this plan is that the equipment will throw shadows on the front wall, but this is of little importance. Projectionists who have used this lighting system prefer it above all others.

The lights in the cove provide sufficient illumination in the projection room at all times for all requirements. Provision should be made in the cove for a secondary circuit to give brilliant illumination when projection is not in progress. The use of this second circuit should be severely prohibited during projection.

Trouble Lamps

When trouble occurs at one of the projectors ample illumination should be concentrated there. (45) For this purpose every projection room should have at least one reel-light; in large rooms two or more reel-lights should hang at convenient points. (46) A reel-light is a lamp at the end of a long cord which is wound on a reel mounted on the ceiling. The lamps can be carried to any part of the room and to every piece of equipment. (47) The reel is spring-controlled, so that the cord will automatically rewind itself and remain out of the way until the lamp is needed. Reel-lights may be bought from any first class supply dealer.

Rheostat Room

(48) If rheostats that are not units of the motor generator equipment are employed to control projection current, they should be located in a separate, thoroughly ventilated room adjacent to the main room. (49) This is necessary not only for the comfort and health of the projectionists, but also as a matter of safety. Hot rheostat grids or coils, and inflammable film, are dangerous combinations in the same room.

Motor Generator Room

(50) Motor generator sets should be located in an airy room adjoining the main projection room. There should be sufficient free space around them to enable all necessary work to be carried forward with reasonable convenience. (51) The generator room should be sound-proofed. (52) Never locate storage batteries in the same room with motor generator sets or other electrical equipment.

Battery Room

(53) Storage batteries should be located in a separate room connecting with the projection room. When charging, batteries give off gases that are injurious if breathed in considerable quantities, and likewise do serious damage to the insulation of electrical equipment nearby. These gases must be exhausted to the outer air as fast as they form.

(54) Wood floors in battery rooms should be covered with linoleum or painted with an acid-proof paint. Battery acid and gases will rot an unprotected wood floor quickly and may cause accidents.

(55) Storage batteries may be adversely affected by extreme temperatures, either hot or cold. They should never be in the same room with rheostats, nor exposed to low temperatures through improperly placed ventilators.

Projection Room Ventilation

(56) Proper projection room ventilation is important

for a number of reasons, each one of which deserves the paramount consideration of the architect and theatre owner. It is important to the health and comfort of the men who work for long hours in a confined space under very difficult conditions at best. It is just as important as a safeguard when a fire starts in the projection room. And, unless removed by lamphouse ventilation, the minutely fine particles of carbon powder given off by the carbon arcs will enter the switches, volume controls and tube sockets of the sound system and lodge on the film, producing minute scratches. Adequate ventilation will avoid all these troubles.

(57) Plenty of fresh air should be supplied—not taken from the auditorium, but outside the theatre. (58) If the room is longer than it is broad, the air should come in near the floor level at each end and find its outlet at the ceiling line at its center, thus sweeping through the entire room. If the room is somewhat square, the air inlet may be at the floor line either at each side or at the rear wall, and the outlet in the center of the ceiling. (59) The inlet opening in all cases should be covered with galvanized wire screen of about one-half inch mesh.

(60) The inlet openings must have sufficient area to admit a plentiful supply of air. Shutters should be adjustable, so that the amount of incoming air can be regulated at will.

(61) The outlet must have ample area, not only for ordinary ventilation but also, in the event of a film fire, to enable the quick escape of all gases and smoke as fast as they form. (62) Otherwise they will seep into the auditorium, perhaps causing fatal consequences. Gases pass quickly through crevices around the glass covers of port openings. When they can't escape they blind and overpower the projectionist, driving him from the projection room. With the fire out of control anything may happen.

If ventilation is by natural draft, both inlet and outlet must be much larger than where forced draft is employed.

(63) Ventilation, save in exceptional cases, should

be by forced draft. The heat generated within the lamphouse is unbearable. Natural air movement may serve in time of cold weather but in the hot summertime it fails utterly to provide the necessary relief. This is particularly true of the South, where warm weather prevails almost throughout the entire year.

But consider the importance of forced draft if a fire in the projection room occurs. By turning on the full power of the ventilating fans as soon as a fire breaks out, the air will be sucked forcibly and rapidly away from the auditorium side and—if the port shutters are closed at once—not even a wisp of smoke or gas will be allowed to pass through the crevices. The audience will not be aware of a fire, though they will guess at some difficulty in projection because of the dark screen. That is better than a panic.

(64) Authorities recommend that projection room ventilation, for reasons of health, should be effected through the theatre's forced draft system where there is one, and that a separate fan and outlet be provided for emergency use only in the event of a fire. If there is no forced draft system, then a fan of proper capacity should be installed in the lower end of the outlet air duct and all inlet air ducts shuttered so that the flow of air may be controlled to meet varying conditions.

For Use in Case of Film Fire

(65) In addition to this it is advisable to install an exhaust fan removed from places where fire is likely to originate. It may be installed in a fireproof cabinet in the main projection room, connecting with an outside air duct. Normally this fan is controlled by a switch held in closed position by a spring, but during the hours of operation it must be open against the action of the spring by means of a strong cord, wire or chain attached to the port fire shutter master control. When, in an emergency, the shutter control is released, it will close the switch, thus instantly putting the exhaust fan into action to the limit of its power. The plan is roughly

outlined in Fig. 71. If preferred the fan may be located entirely outside the projection room.

(66) The method may be utilized in either of two ways. The fan ordinarily may be used to ventilate the projection room by installing a speed control device so that it will operate at the required speed. The speed control must be so connected to the port shutter master control that when it is released it will instantly energize the fan to its full power.

The other way, when there is no forced draft system, is to install a separate, smaller fan in the outlet duct for ventilation purposes only, using the large fan for emergencies like fire. In this case it will incur no operating expense nor will it suffer deterioration from wear. It has a distinct value as insurance against the possibility of panic in the event of fire.

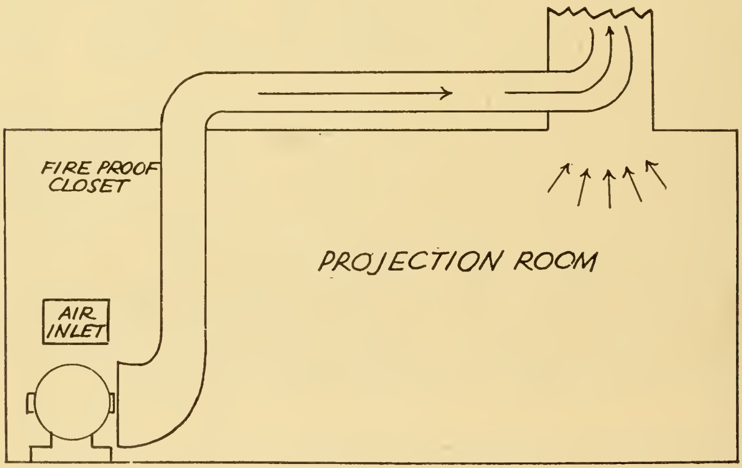

FIGURE 71

(67) To be effective the fan must be large enough to create a slight vacuum in the room; therefore it must be arranged to permit the inlet opening shutters to close automatically as soon as the port shutter master control is released. An auxiliary switch should be provided to open the fan circuit when the port shutter master control is released normally, as at closing time.

(68) In Fig. 71 it will be observed that the arrangement provides for an air injector, or ejector if you like that term better. It is very powerful in creating air movement.

(69) The air outlet should be of fireproof material, well insulated from all combustible matter nearby. There must be no sharp bends or elbows in the exhaust duct. The fan can be installed in the lower end of the duct itself provided the duct has sufficient diameter, and the fan can be geared to a well-protected motor. (70) Do not install the motor in the duct because it will be in the path of hot air and possibly flame and would be put out of commission immediately in case of an open film fire. The accompanying drawing is designed only to convey the general idea. Details of installation will vary widely for each theatre.

(71) What is wanted is plenty of fan power that will cut into maximum power the moment a fire starts, the driving motor well protected from heat.

Painting the Projection Room

(72) When the cove trough method of lighting is employed use non-gloss paint because it has least light reflection powers. A gloss white paint is best for the portion of the ceiling at the rear of the cove trough, and on the upper portion of the rear wall. The lower portion of the rear wall, the entire side walls and the front wall should be in either dark olive or dark brown color, well stippled to reduce reflection. The ceiling in front of the cove trough may be any color, but a light buff is suggested. It is, perhaps, not a pretty room, but it serves projection requirements most efficiently.

(73) Where the room is lighted in the usual manner, the rear and side walls, including all doors, should be painted a dark color, preferably an olive green or dark brown, seven feet high in an 8-foot ceiling room or eight feet in a higher room. The front wall should be darker than the walls—the darker the better. Dark olive green or its equivalent in brown will serve well. (74) All front wall metal work and an eighteen-inch area surrounding

observation ports should have two coats of flat (non-gloss) black.

(75) The walls and ceiling of the battery room, rewind room, motor generator room, toilet and all other rooms should be painted a light color, preferably cream or buff. The first four feet above the floor should be a dark color, which won't show finger marks and other discolorations.

Port Fire Shutters

(76) All port fire shutters should be of about No. 10 gauge iron. Consult your local fire authorities for any special ordinances on this subject.

A fire in the projection room seldom does any extensive damage. (77) It is the sight of smoke by the audience that starts all the trouble. (78) The real purpose of port shutters is not so much to confine the

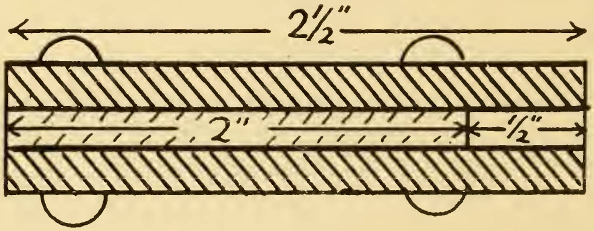

Figure 72.

actual fire, as it is to prevent theatre patrons knowing that there is any fire—to keep the smoke as well as the blaze entirely from their view.

Shutter grooves should therefore be made to fit the shutters snugly but without danger of sticking. (79) The grooves should be mounted level on the wall. They should be not less than one-half inch deep, allowing the shutter one-eighth inch clearance on either side when moving up and down.

Grooves may be made by using the three pieces of scrap iron as shown in Fig. 72, each ⅛ of an inch thick. The three pieces are riveted together, and bolted to a level space on the wall.

The bottom crosspiece is made in the same way but its groove is one inch deep with (80) a half-inch strip of soft sheet rubber laid in it edgewise to deaden the noise when the shutter is dropped. (81) It is possible to purchase ready-made metal port casing already provided with shutter grooves and a groove for the cover glass of the observation port. These casings are adjustable for different wall thicknesses. Their use is recommended though hand-made jobs are equally satisfactory.

Shutter Suspension

The chief service of the shutter is to prevent audiences from recognizing fire. To do this successfully the shutters must drop quietly within two or three seconds after the fire starts. The idea of placing metallic fuse links near the ceiling is correct theoretically, but it does not always work out well in practice, especially if the fire produces plenty of smoke but very little heat.

(82) To be sure of a quick-acting shutter it is essential that a quick-action fuse be installed where the flames will reach it the instant a fire blazes up. This is a very important precaution since a delay, even if measured in fractions of a second, may provoke considerable harm.

(83) No unusual powers of reasoning are required to understand that a metallic fuse is almost totally useless for prompt action where a film fire is confined to a closed projector magazine, from which it exudes relatively little heat but an enormous volume of smoke. It is wholly useless if it is located at any considerable distance from the magazine. Its location on the ceiling does not lessen its ineffectiveness. As soon as a fire starts, projectionists must attend to closing the shutters at once. It is a moment when life must be considered as more important than property.

Glass in Ports

(84) Since the advent of sound it has become necessary to confine all noises incident to projection to the projection room itself. (85) Optical glass is used to

cover ports but optical glass is relatively expensive and often good plate glass will serve as efficiently.

Optical glass should be used for the projector and stereopticon lens ports, but is not necessary for either observation or spotlight ports. Good plate glass will not distort either vision or a spotlight beam. It probably has minute bubbles or stresses that might visibly affect the projector light beam but it would have no appreciably bad effect when used in stereopticon or effect projector lens ports.

Optical glass, therefore, is recommended for the projector lens ports and if preferred for the stereopticon and effect projector lens ports. For observation and spot lamp ports we recommend the use of a good grade of plate glass.

(86) Be careful that the projectionist's line of vision when he is standing beside the projector is not obstructed by light reflected from the surface of the cover glass over the ports. This can be avoided by setting the glass at an angle. The angle will vary according to the conditions of each projection room; therefore no fixed angle from the perpendicular can be named.

(87) The glass in all ports must be mounted to make the outer surfaces conveniently accessible for cleaning —an important item that must not be overlooked. This may be accomplished in one of several ways. The glass may be mounted in a metal frame and this, in turn, mounted in a second metal frame to be hung on the wall; the frame holding the glass is hinged to the bottom of the wall frame, so that its top may be pulled back and the glass cleaned conveniently. Or the glasses may be set in grooves, except for one objectionable feature: the glass is subject to frequent breakage because it is handled so much.

Lens Ports

We do not favor covering the lens ports with glass unless tests prove it to be really necessary. (88) If the lens ports are reduced to approximately the dimensions of the light beam the openings will be so small that no sound passing through them will annoy any in the audience except perhaps the few who sit close to the ports. The method of reduction is illustrated in Fig. 69.

To make sure, sit in the seats nearest the open ports during performances. If there is not enough noise to annoy you, it will not bother anyone else. (89) Keep the lens ports open if possible—you will eliminate loss of light through reflection from both surfaces of the glass cover, and glass can never be perfectly cleaned—a faint finger mark may spoil an otherwise splendid projection. Lens ports can always be open during relatively small matinee performances.

Projection Room Entrance

Entrance to the projection room should be comfortable and convenient. If a stairway is necessary it should be of normal grade and safety. The day of mounting a perpendicular ladder, or climbing into the projection room through a hole in the floor is decidedly past and local building safety regulations should be invoked to force a change.

(90) The door should be of ordinary height and never less than twenty-four inches clear width when it is open. (91) If the main entrance of the projection room leads directly into the auditorium then there should be two doors, with not less than three feet between them to form a hallway. Among other advantages this hallway is one more protective factor, in the event of fire, to keep the audience in blissful ignorance of the trouble until it has filed out.

(92) All projection room doors must be fireproofed. There is a door approved by the Underwriters for such use. It is known as the "Kalamein," of which there are two kinds. Use only the one bearing the Underwriters' label, as it influences insurance rates. This door is made of layers of white pine covered with metal.

The door should be kept closed at all times during projection while an audience is present.

Instrument Board

It is a serious error to use the various ammeters, voltmeters and other controlling gadgets in diminutive form. All meters should be big enough to be plainly visible and should be placed on a panel board located immediately beside the observation ports within easy view of the projectionist. Their dials should be dead black in color (non-gloss); the figures, division marks and needles in white.

What Constitutes a Good Projection Room

(93) The following qualities are essential to any comfortable, well-planned projection room:

Located so that a point midway between the two motion picture projector lenses will be equi-distant from a line at right angles to the screen center.

So located, as to vertical height, that distortion will not increase picture height in excess of five per cent of normal height.

So located that the projection lens E.F. will not exceed four and a half inches E. F. minimum and seven inches E. F. maximum.

Thoroughly fireproof so as to confine fire within its own walls.

All port shutters capable of closing automatically within three seconds of inception of fire at either the projector aperture, film storage reservoir or rewinder.

Port fire shutters to allow either instantaneous manual or automatic operation.

Provision to pump out smoke and gases rapidly enough to maintain a slight vacuum in the room, so that no smoke escapes through crevices into the auditorium.

The floor must be wholly vibrationless.

All illumination to be behind the projectionist as he stands beside the projectors.

No light to be openly visible except when direct light is necessary in case of trouble.

There should be a separate light circuit for brilliantly lighting the room in time of trouble, and one or more reel-lights for use in working around machinery. The front wall should be painted flat black. Next in efficiency is some dark, non-reflecting color, such as green or brown.

All projection room entrance doors should be kept closed—not on a lock but by means of a spring, and should be reached, where necessary, by proper, safe stairways.

It should have proper ventilation.

The fresh air inlet must be connected either with the theatre ventilation fresh air inlet, or directly with the open air.

All wires must be in concealed conduit, and all conduit thoroughly grounded.

Fuses and switches should be enclosed in metal casings or cabinets, or in cabinets built into the walls and covered with metal doors.

Projector circuit wires should emerge from floor almost exactly at the rear of each projector lamphouse.

Proper steel cabinets for tools and projectionists' clothing should be provided.

A room adjacent to the main projection room should be equipped with work bench, a combined vise and anvil, all proper tools, and an upright hand drill carrying an assortment of drills.

All switches and apparatus should be within easy reach of the projectionist.

Observation ports should be large enough to give the projectionist a clear, unobstructed view of the screen.

Sanitary necessities such as a toilet with running water and a wash basin with running water (both hot and cold if possible) should be arranged close to the projection room. A shower may well be added, especially in warm climates.

Telephone connection to manager's office and other points about the theatre.

A fireproof film storage reservoir, each reel compartment supplied with water and connected by fireproof duct to the open air.

A special emergency switch with which the projectionist can illuminate the auditorium if necessary.

CURRENT RECTIFICATION

1. Of what does current rectification consist?
2. What is the prevailing current served to theatres here and in Canada?
3. By what means is current rectified?
4. What purposes do current rectifying devices serve?
5. What is ballast resistance?
6. How much more can generator voltage exceed arc voltage?
7. What theatres can use the newer a.c. arcs?

The Mercury Arc Rectifier, page 277

8. Is the mercury arc rectifier still in use?
9. Name the objections to mercury arc rectifiers.
10. Name the points in favor of mercury arc rectifiers.
11. Describe the vacuum tube contacts and seals.
12. Through what does the mercury arc rectifier receive its current?
13. Is it possible to regulate the current flow?
14. How is a mercury arc rectifier put into action?
15. What happens inside the vacuum tube when an electric spark is generated?
16. What do contacts A and A1 in Fig. 73 represent?
17. By what process between contacts A and A1 in Fig. 73, is direct current produced?
18. Why should mercury arc rectifiers not be placed in the main projection room?
19. Should a spare tube always be carried in stock?
20. What is the regulating reactance?
21. Is it possible to operate two arcs off one rectifier?
22. Are vacuum tubes used to rectify a.c. into d.c.?

Vacuum Tube Rectifiers, page 281

23. Are vacuum tubes used to rectify current for projector light sources?

24. Name the various parts shown in the diagram Fig. 74 A.
25. Why does not the secondary (Fig. 74 A) short circuit the filament?
26. How much resistance has the filament?
27. What does the filament do when it is heated to incandescence?
28. What are two important points concerning the filament and electrons?
29. What does the upper secondary coil (Fig. 74 A) do?
30. How is a vacuum tube charged at each alternation of current?
31. Why do the electrons rush to the plate when it is positively charged?
32. In which direction does electricity flow as indicated by vacuum tube rectifiers?
33. Is the flow of electrons from filament to plate free?
34. Trace the current flow in Fig. 74 A.
35. What happens when the positive plate becomes negatively charged?
36. May more than one-half of each a.c. wave be used with one tube?
37. Describe the action occurring in diagram Fig. 74 B.
38. What kind of a rectifier is the one wired as shown in Fig. [redacted]?
39. What two types of tubes can be used as rectifiers?
40. What type is preferable?
41. What part of a tube rectifier may give trouble?
42. Should the transformer temperature be checked occasionally?
43. Will the failure of one tube cause the rectifier to fail entirely?

"Stack" or "Disc" Rectifiers, page 287

44. Can the stack rectifier be made in any desired capacity?
45. Does the stack rectifier require attention after installation?
46. Does the rectifier make any noise or vibration? Does it affect the sound?
47. What is represented in figures 74 D and 74 E?
48. What is represented in figure 74 F? Explain the action illustrated in it.
49. To what is the rectification action attributed?

50. What purpose does the lead washer serve?
51. How is pressure between copper and lead secured and retained?
52. Is the exact amount of pressure important?
53. Of what does the commercial form of copper-oxide rectifier consist?
54. Do copper-oxide rectifiers require replacement of parts or demand attention?
55. Is the proper operation of the ventilating fan important? What protection is there against the failure of the fan?
56. How does the efficiency of these rectifiers compare with that of other current rectifiers?
57. What other substances beside copper-oxide are available for rectifying purposes?
58. Are rectifiers available for all phases of a.c.?
59. Where should copper-oxide rectifiers be located?
60. Is it practical to overload them?

Motor Generator Sets, page 295

61. What is a "brush"? Has it many varieties and what purpose does it serve?
62. What is meant by "brush loss"? How does it occur?
63. What is meant by "brush pressure"?
64. What should be the limits of brush pressure?
65. What difficulty does too much or too little brush pressure cause?
66. How may brush pressure be measured?
67. What is the brush rocker or yoke? How should it be set?
68. What is a compound-wound generator or motor?
69. What is the effect of compound winding of motor field magnets?
70. What is a commutator and what is its function?
71. What condition is indicated by a commutator "flat"?
72. What is a commutator "lug" and what is its purpose?
73. What is meant by a parallel connection of dynamos or alternators?
74. What is polyphase current? How is it produced?
75. What is the amperage and voltage of dynamos connected in series?
76. What is the effect of a series wound dynamo?

77. What is a shunt?
78. What is a shunt wound field?
79. Describe a shunt motor.
80. Describe a squirrel cage winding.
81. What is meant by a shunt wound dynamo?
82. What is a synchronous motor?
83. What is a synchronous polyphase motor?
84. What is an undercut?
85. What is the current producing element of a motor-generator set?
86. Name two reasons why most motor-generator sets have an a.c. motor.
87. Why is a d.c. motor-generator installation inadvisable where d.c. at 110 volts is available from power lines?
88. What double purpose does the motor generator set serve?
89. What efficiency should a good motor-generator set have?
90. How should the motor and generator be mounted?
91. What two types of generator are generally employed?
92. What are the facts of the development of the generator in motion picture work?
93. Why is the once popular series type generator no longer employed?
94. What is meant by ballast resistance?
95. Name the conditions that exist when parallel type generators are used.
96. What must ballast resistance do without over-heating?
97. What are the limitations of ballast resistance capacity?

To Parallel Compound-Wound Generator, page 306

98. Why is it necessary to use an "equalizer" between two compound-wound generators?
99. What is an equalizer?
100. If one cold compound generator is cut into the circuit of another already in operation, what happens?

Alignment of Motor and Generator, page 307

101. Must the motor and generator be very carefully aligned?
102. How can the alignment of shafts be tested?

103. What is the effect upon motor generator sets if improperly handled?

104. What elements of a generator demand attention if it is to operate at a maximum efficiency?

EFFECT OF RESISTANCE, PAGE 309

105. How much ballast resistance is permissible?

106. How does ballast resistance affect the flow of current?

107. What is the usual range of generator voltage above the arc voltage.

108. How does the arc feed affect ballast resistance?

OIL AND DUST, PAGE 309

109. What is the effect of oil on insulation?

110. Do dust deposits reduce generator efficiency?

WORN BEARINGS, PAGE 309

111. What serious condition is induced by worn bearings?

112. Describe the methods of checking bearings.

113. What tool is frequently used to test clearance between armature and pole pieces?

114. How can worn bearings be detected with a bar?

LUBRICATION, PAGE 310

115. Describe the oil well of a sleeve-type bearing? How is it lubricated?

116. How often should the motor be lubricated?

117. Will any ordinary oil suffice for a motor-generator?

BALL BEARING LUBRICATION, PAGE 312

118. What two common constituents of oil must be avoided in ball bearing lubrication? What must be done in the matter of selecting grease for ball bearings?

Installation Suggestions, page 312

119. What first inspection should be made in a newly acquired generator?
120. Do all motors require a starting box?
121. What should be the capacity of the wires?
122. Does the Underwriter's rated capacity insure economic operation?
123. How do you arrive at the best wire sizes?
124. In selecting wire sizes is it necessary to provide for future increases in current consumption?
125. How is the voltage drop of a circuit calculated?
126. When is it wise to know the performance curve of a generator?

Installation, page 313

127. Where should a motor-generator set be located?
128. What are the objections to placing the generator too far from the projection room?
129. Can a generator be mounted on springs to absorb vibration?
130. Should there be plenty of clear space around the generator?

Brushes, page 315

131. What is important with regard to commutator brushes?
132. What is the correct method of fitting brush ends to the commutator surface?
133. What is best evidence that a commutator is in good condition?
134. How is the correct setting of the rocker arm (brush yoke) indicated?
135. What is the correct pressure in pounds for each square inch of brush surface?
136. If scale measurements show that brush pull varies, what condition is indicated and how can it be corrected?
137. How would you calculate brush pressure on contact surface?
138. How may brush pressure be measured by means of a rubber band?

Care of Commutator, page 317

139. What results from a commutator sparking?
140. What deficient elements invariably cause trouble?
141. How should a commutator be brushed?
142. How can the commutaor surface be cleaned right down to the copper?
143. After sanding a commutator what should be done before it is put in operation?
144. What is a commutator stone and how is it used?
145. After using a commutator stone what must be done?
146. Describe the method of making a commutator lubrication pad.
147. Should there be any sparking if the dynamo is not overloaded?
148. What causes sparking?
149. How are high commutator bars usually detected?
150. What does a slight motion of the brushes in the holder indicate?
151. How would you test for an out-of-round commutator?
152. Summarize the items on a commutator that need watching and correction?
153. Why do brushes stick in their holder? How can it be corrected?
154. Do commutator bars wear thin and require replacing?
155. Do soft commutator bars wear faster?
156. What does an overheated brush indicate?
157. Do worn bearings cause excessive sparking at brushes?
158. What occurs when an armature coil is short circuited?
159. How is a sprung (bent) armature shaft evidenced and what should be done about it?
160. What are the results of overloading?
161. Will a properly designed generator stand overloading? Is it good practice?
162. What would you regard as evidence of a weak field? How does it affect the motor?
163. What causes a weak field? How would you test for it?
164. If you discover excessive vibration in a new generator set, should it be refused?
165. What does a ring of fire around the commutator indicate? What should be done?

166. What causes a ring of fire to appear in the amature? Where do you look for an open circuit?

167. What will cause the armature to become overheated? What may happen?

HOT BEARINGS, PAGE 324

168. If a bearing runs hot what should be done?

169. Should water be used to cool down a hot bearing?

170. How may a hot bearing be cooled down?

171. What must you avoid when bronze bearing runs hot?

PERMISSIBLE TEMPERATURES, PAGE 325

172. If any part of a motor or generator feels warm, does this indicate something wrong?

173. What is the allowable temperature of machine parts?

174. How can the temperature of a machine part be measured?

CHAPTER X

CURRENT RECTIFICATION

We shall here deal with current rectification only as it applies to projector, stereopticon and spotlight light sources. Rectification for sound purposes will be dealt with elsewhere.

(1) Current rectification consists of changing alternating current into direct current, or a close approximation thereof, through some instrument other than a dynamo commutator. It may be accomplished by any one of the various devices described below.

(2) With few exceptions, theatres everywhere in the United States and in Canada are served with alternating current, usually at 110 or 220-volt pressure, 60 cycles.

Aside from one new type of high intensity, alternating current light source now enjoying considerable favor in the smaller theatres, the alternating current arc is not suited to projection work. It is noisy. It makes it difficult to maintain steady screen illumination. The energy of the current being divided between the two carbon tips, upon each of which a crater is formed, only one of which is available for use, it requires a very much higher amperage to secure screen brilliancy equal to that produced by the d. c. arc.

The usual practice therefore is to rectify the current, and thus have direct current at the projector light source.

(3) This may be done either by means of a mercury arc rectifier or by applying a. c. from the service lines to an a. c. motor coupled to and driving a d. c. dynamo, or by other recognized means.

(4) Whatever the rectifying device may be it serves two important purposes, namely (a) it receives a. c.

and delivers d. c. to the projector light source. (b) It receives current at line voltage and delivers voltage at the arc as low as is consistent with efficient operation.

(5) To secure the required stability and steadiness in illumination the supply voltage should be somewhat higher than the arc voltage, and the difference is broken down by what is known as "ballast resistance," which is the name applied to the rheostats used for that purpose. (6) The difference must not be less than fifteen volts, though the exact amount varies according to the character of arc. Any unnecessary pressure means waste of power.

(7) It is quite possible to project motion pictures with an a. c. light source. Many small theatres are doing so, using a special type of a. c. arc made possible by special carbons. This is good practice only for theatres requiring a light source of limited power.

Let us examine the various devices designed to receive alternating current and supply projection light sources with direct current.

The Mercury Arc Rectifier

(8) The mercury arc rectifier was commonly used for current rectification some years ago. It has been very largely displaced by motor generators and rectifiers of other types.

(9) There are many objections to mercury arc rectifiers for motion picture projection. They are limited in capacity. They will not stand for any overloading. Tubes are costly and of uncertain length of life. Some tubes will operate for a long interval; others will burn out, for no discoverable cause, in a few hours. The tubes give off a rather weird light, a pronounced hum, considerable heat and break easily. The d.c. drawn from them is often very irregular.

(10) On the other hand the mercury arc rectifier is light in weight as compared with a motor-generator set. It is relatively low in first cost. Its efficiency is high—there is relatively little loss through power absorption, though the tube upkeep is considerable. Voltage reduc-

tion is accomplished through transformers, which are very efficient.

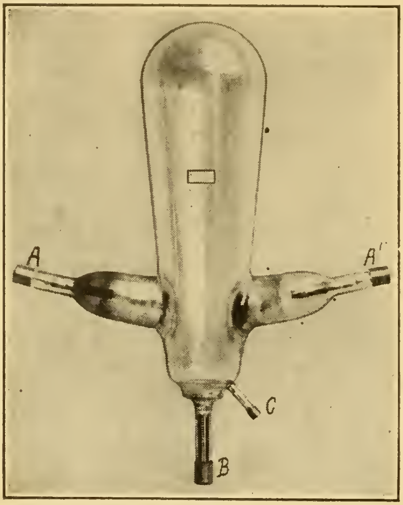

FIGURE 73

(11) Fig. 73 shows the mercury arc vacuum tube. A and A1, at the end of the side extensions of the tube, are metal clips that connect through air-tight seals with a lug, of graphite or some other material, inside the tube, Extensions B and C are filled with mercury which forms an electrical connection through an air-tight seal with the metal clips on the outer surface of the tube.

The action is as follows: (12) All current is supplied through a main reactance consisting of a specially designed transformer from the secondary coils of which the input connects directly with the positive carbon of the arc. (13) All good rectifiers designed for motion picture work have a regulating reactance by means of which amperage at the arc may be varied, within certain limits, but in no case in excess of the capacity of the rectifier vacuum tube.

(14) We will assume the rectifier to be idle, but connected to the current supply and ready to operate. On closing the main switch a "shaking magnet" tilts the tube sharply sidewise, which forces lugs BC (Fig. 73) to move upward to the left so that the mercury in them is thus brought into contact, whereupon the tube is rocked back to an upright position. This new action causes the mercury to separate again, and at the instant of breaking contact an electrical spark is formed.

(15) The spark vaporizes and ionizes enough of the mercury to fill the whole tube with mercury vapor—a state in which it is an excellent conductor of current.

(16) Remember that lugs A and A1 are charged with voltage from the secondary circuits of the main reactance, usually located at the bottom of the rectifier. Consider, too, that A and A1 are connected to opposite sides of the secondary. In other words, A represents one side of the a. c. supply and A1 the other. Remember also that voltage is supplied, through the vapor, between A and A1 and lug B.

(17) Referring to Figure 74, note that C of Figure 73 is wired in series with a "starter anode resistor" which limits the current that can flow through it, and hence reduces C to a state of practical unimportance except as one of the electrodes for the starting spark. The remainder of the action of this rectifier lies between A, A1 and B.

Assuming the a.c. line entering Figure 74 at the top to be of 110 volts, there is a drop of 55 volts across each of the two main reactance coils connected in series across that line. The wire that runs left and downward from the center point between those coils is then negative by 55 volts with respect to whichever of the two wires is positive at any given moment. This center-tap wire may be traced through the arc itself (labeled "lamp" in the drawing) and through a protective relay to B of the rectifier.

B is in contact with a pool of mercury inside the rectifier tube. The starting spark has heated some of the surface of this mercury and caused it to emit electrons. Those electrons are attracted to either A or A^1—whichever of the two is at the moment 55 volts positive with reference to B, and form a conducting path from B that anode. On the next cycle, electrons are repelled from that contact (which has become 55 volts negative with respect to B) and attracted to the opposite side extension of the rectifier. By virtue of this action a continuous current flows from B through the rectifier, alternately leaving the rectifier at A and at A^1. This direct current flows through the projection arc, which is in series with B.

One technical correction must be applied to the above. The difference in potential between B and A and A^1 actually is not 55 volts, but in the order of 15 volts, the other 40 volts having been absorbed in the potential drops across the projection arc and the relay coil.

Certain Practical Points

(18) Mercury arc rectifiers should be located near, but outside of the main projection room. They produce a decided hum, which would be objectionable in the main room. Unless the tubes are painted black (which may be done without injury to them), they give off a disconcerting bluish light. They should not be placed close to

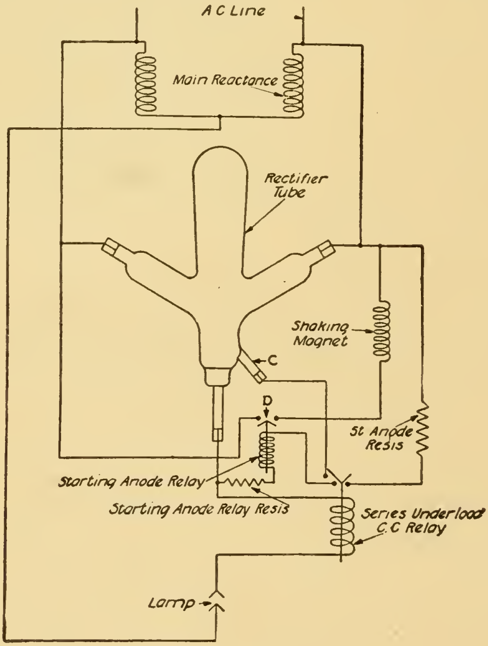

Figure 74

sheet metal, because the main reactance may set up a vibration in the metal—producing more annoying sounds. Mercury arc rectifiers, being light weight and having no moving parts, require no special foundation but may be set up on the floor.

Rectifier tubes may last one day or a year, though these are extreme intervals. Always test a new tube by rolling the mercury from end to end. If the vacuum is good there will be a sharp clicking sound. If no such sound is heard, reject it.

(19) Always have a spare tube in stock. Tubes should and usually will last several months, provided they are not overloaded or otherwise abused.

Fig. 74 shows the wiring set-up in simple form. The regulating reactance and several other devices are not shown.

(20) The "regulating reactance" is really a choke coil controlled through a dial switch or its equivalent located on the rectifier panel. It operates to reduce the

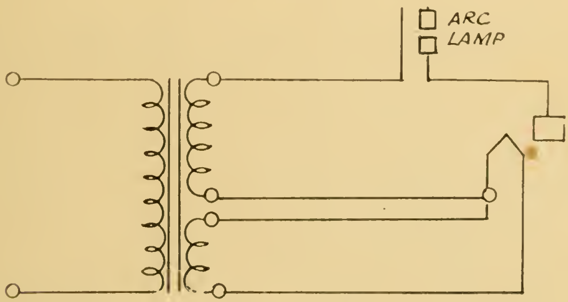

FIGURE 74A

voltage to force through any desired amperage, within the capacity of the tubes against the resistance of the arc.

Two Arcs from One Rectifier

(21) It is quite possible to operate two arcs from one rectifier, though not both at the same time. Manufacturers will supply the additional equipment needed to change from one light source to the other without putting the tube out of operation.

Vacuum Tube Rectifiers

(22) Vacuum or gas-filled tubes are now widely used to rectify a. c. into d. c. (23) They are even being employed to rectify current for the light source of the projectors, and hence it is important that projectionists know the fundamental principles that govern their

action. Figures 74A, 74B and 74C offer a diagrammatic presentation of these principles.

(24) Fig. 74A shows, at the extreme left, a diagram of a transformer with two secondary windings. The lower winding is connected directly to the vacuum tube filament; the upper winding is connected to the vacuum tube plate through the arc. Observe that there is no metallic connection between the plate and the filament and so under ordinary conditions no current could or would flow.

(25) The lower transformer secondary would "short circuit" the filament were it not for the filament resistance. (26) The resistance permits just enough current to flow to raise the filament temperature to incandescence, (27) and in this condition it emits or throws off clouds of electrons, which may be regarded as minute particles of negative electricity. (28) Two points to remember are that at incandescence the filament emits and is surrounded by clouds of electrons floating in the vacuum and that these electrons are always negative.

(29) The upper or plate secondary of the transformer operates to charge the plate alternately with positive and negative voltage.

(30) To understand the action of a vacuum tube rectifier, consider first the period of time during which the plate secondary is positively charged, remembering that it will be positively and negatively charged at each alternation of the current.

(31) At the moment of time it is positively charged, the plate will also be positive. Therefore, since opposite polarities attract each other, it follows that the negatrons that hover around the negatively charged filament will rush to and enter the positive plate and continue to flow outward to and through the arc, constituting the current by which it is operated.

(32) Remember, when you note that the plate connects to the lower or negative arc lamp carbon, that today electricity is regarded as really flowing from negative to positive—a theory that seems proven by the action of vacuum tube rectifiers.

Mercury Arc Rectifier Trouble Chart

- **TUBE DOES NOT START.**
  - See if there is voltage and if it is up to normal.
    - **TUBE DOES NOT TILT.**
      - No current at tube terminals.
        - Current at switch—Fuses blown.
        - No current at switch—Line voltage off
      - Relay contact not closed
        - Friction or bent stud.
        - Relay contact is poor.
        - Tilting circuit open.
        - Secondary coil of magnet short circuited.
    - **TUBE TILTS.**
      - Amalgam bridge between electrodes—Install new tube.
      - D. C. circuit open.
        - Lamp circuit open.
        - Carbons not making good contact with each other or with the lamp jaws.
- **TUBE TILTS**
  - Does not return to vertical.
    - Lead on starting anode broken or loose.
    - Mercury pools do not make contact.
    - Friction in tube holder.
      - (Mercury pools do not make contact / Friction in tube holder:) Adjust tube; it does not tilt far enough.
  - Returns to vertical without flash after repeated tilts.
    - Tube is defective.
    - Tube has lost its vacuum.
      - (Both:) New tube.
  - Flashes and goes out.
    - Lead to positive electrode anode loose or broken.
- Tube continues to tilt after starting.
  - Relay does not open the circuit.
    - Winding short-circuited, friction or bent stud.
- Tube goes out.
  - Lamp carbons separated too far.
- Tube tilts feebly.
  - Voltage of circuit low.
  - Frequency of current not right.
  - Friction in tilting mechanism.
  - Tube is too heavy at bottom.
- Outfit is noisy.
  - Reactance coil loose on frame.
  - Reactance coil air gap not wedged tight.
  - Cover vibrates.
  - Operating room floor vibrates—set outfit on felt pads.
- Arc is noisy.
  - Carbons too hard—use softer ones.

NOTE—When proper vacuum exists the mercury gives off a sharp clicking sound when it is run from one end of the tube to the other. Absence of this sound and the presence of air bubbles show loss of vacuum.

Tube may be defective by short-circuiting between starting anode and cathode. When in this condition it is badly blackened.

(33) While the tube plate is positively charged the flow of electrons from filament to plate is as free as though these two elements were connected by wire, making due allowance for differences in resistance. So long as the plate remains positive the arc circuit may be traced by following the current direction from negative to positive: (34) from the lower or negative end of the filament secondary to its center tap, thence to the filament and thence around its secondary coil circuit. From this current come the emited electrons which flow through the plate and arc, and thence back to the upper transformer secondary.

(35) Passing on to the consideration of the next succeeding alternation of the mainline current, we discover that the secondary has reversed its polarity, which means that the plate is now also negatively charged. Since the electrons emitted by the filament are always negative, and like does not attract like, no electrons will flow to the plate, and therefore none to the arc. (36) Hence, as regards a single plate, only one "side" of the a. c. alternations can be used. Current flows through one-half of each alternation, but none flows during the succeeding half. Therefore, with one tube, we will have direct but very highly pulsating d. c. at the light source. All this is illustrated in Fig. 74A but it is a very undesirable type of rectifier for projection. Let us consider one more suited to the work.

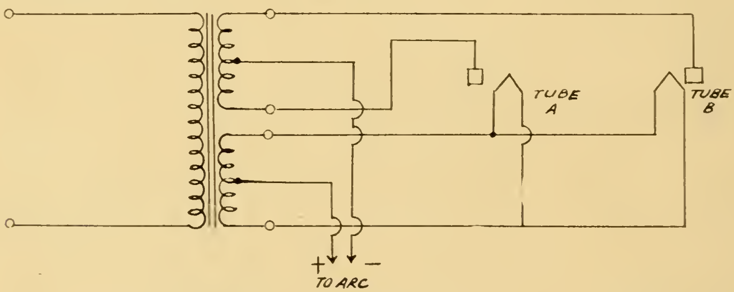

FIGURE 74B

(37) Fig. 74B shows a modification of Fig. 74A. The secondaries of the transformer are center-tapped,

for use with two tubes instead of one. The plates of the tubes are connected to opposite ends of the plate secondary, hence A plate will be positive (and carrying cur-

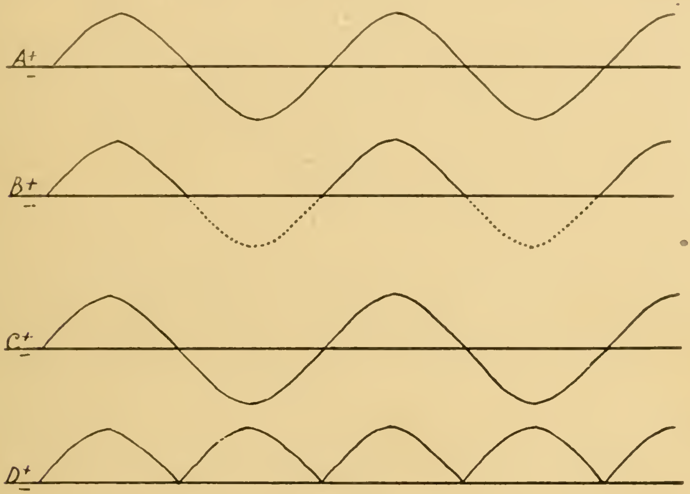

FIGURE 74C

rent) when B plate is negative, and vice versa. The lower secondary of the transformer lights the filaments, and also serves as part of the conducting path for the circuit originating in the upper secondary. Electrons flow from either filament to the plate that is positive at the moment, thence to the center-tap of the plate secondary, thence through the projection arc, thence to the center-tap of the filament secondary, and thence back to the filament from which they were emitted. The current through the arc is always in one direction, but drops to zero twice in each cycle, at those moments when the charge on one plate is just changing from positive to negative while the charge on the other is just changing from negative to positive. The pulsations in d.c. output are, however, much less than in the case of Fig. 74A, in which no current at all flows through the arc during a full half of each cycle. (38 The difference is diagrammatically illustrated in Fig. 74C in which A represents the "full wave" a. c. wave and B the portion (above the line) used by the half wave rectifier. C is the full wave a. c. and D the resultant d. c. wave of the full wave rectifier.

Whenever a high amperage, or a current of exceptional smoothness, is required, it is possible to use a 3-phase rectifier which has six tubes. It is the circuit shown in Fig. 74B repeated three times—once for each of the phases of a 3-phase transformer, the d. c. outputs being wired in multiple.

Types of Rectifying Tubes

(39) Tubes used for arc light source supply rectifiers may be either of the vacuum or gas-filled type. (40) The presence of some gases increases the current flow

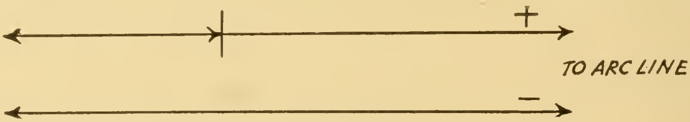

Figure 74D

through the tube by increasing emission of the negative electrons from the filament. Tubes of 5, 10 and 15, and 30 ampere "space current" capacity are used in these rectifiers.

Maintenance and Care

(41) Tube rectifiers such as we have described have no moving parts, so there is nothing except the tubes themselves to wear out or cause trouble. Sometimes—but rarely—the transformer may burn out through overheating. Usually the primary coil is tapped to permit compensation for high or low line voltage. (42) Their temperature should be checked occasionally and if found to be consistently high, proper compensation should be made to reduce primary voltage. Usually a tap switch is provided for the purpose.

(43) If either tube shown in Fig. 74B should burn out, the rectifier will not stop working entirely but will continue to function as a half-wave rectifier. Screen illumination will be cut down by one-half and the light will start to flicker. Tubes rarely burn out but do de-

teriorate with age, resulting in a gradual decrease in current output. A new tube is the only remedy.

"Stack" or "Disc" Current Rectifiers

The stack or disc type rectifier has been in use in small units for a long time. (44) Only recently has it been developed commercially in sizes sufficient to deliver as much as sixty-five amperes. It can now be made to deliver any desired amperage. It deserves our consideration because it is so sturdy and durable. (45) Once installed it requires no care save an occasional dusting and careful inspection every thirty days to make sure its electrical connections are in good order. (46) It makes no bothersome noise, it is free from vibration and has no effect on most types of sound equipment even if located a few feet away.

(47) Fig. 74D is a symbolic illustration of the circuit of a single unit, half-wave rectifier of the stack or disc type. The arrowhead and cross line in the upper line is the conventional symbol for a stack or disc rectifier. So long as the wire on the arrowhead side is positive, the unit will pass current. When, however, the a. c. reverses its direction and that wire becomes negative, current can no longer flow, as will be explained. Fig. 74E is an assembly of units in the form put out by one manufacturer. Its action is symbolized in Fig. 74D. Current will flow through this unit only during each alternation or half cycle. It is therefore a half-wave rectifier.

Figure 74E

(48) In Fig. 74F we see a circuit representing four such units, 1, 2, 3 and 4, so connected that each will pass current through opposite half cycles. When the half cycle occurs that causes the upper wire of the a. c. line to be positive (we are considering the flow of current from positive to negative—if the direc-

tion of flow is regarded the other way, just reverse the plan), rectifier 1 will pass current, which will flow downward to the left point of the diamond (the apparatus itself

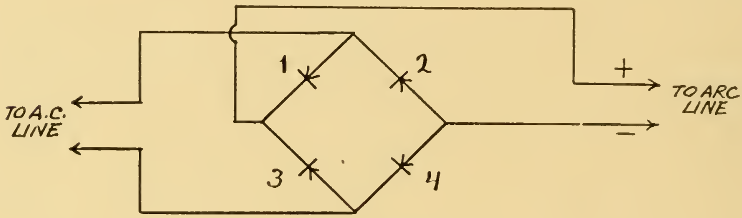

FIGURE 74F

is not diamond-shaped), then upward and on to one pole of the arc. Rectifier 2 is closed to current passage because it is connected with its arrowhead facing the positive side of the line.

When, however, the current reverses, the action is reversed and current will flow through rectifiers 2 and 3, but not through rectifiers 1 and 4, which, as you will see, sends the second half of the cycle on to the arc in the same direction as the first, whereupon we have a full-wave action of the rectifier.

Reasons for Rectification Action

(49) Just how rectification occurs is not yet thoroughly understood. It is believed to be due to electronic action between plain copper and copper oxide. Each rectifier unit consists of a stack of alternate copper and lead washers, or "discs." By proper treatment a microscopically thin coating of copper oxide is formed on one side of the copper. The combination of copper and the coating of copper oxide possesses the peculiar property of passing current in one direction but not in the other. By connecting a conductor to the plain side of the copper and another to the oxide coating we have a half-way rectifier of very limited capacity.

(50) The oxide coating is too thin to connect to in the regular way, so proper connection is effected by pressing a lead washer upon it. (51) The washer must be held in

permanent intimate contact with the surface. A bolt is used, the end of which may be seen in Fig. 74E.

(52) The precise degree of pressure of the lead washer upon the copper oxide coating is still a problem. Too much or too little pressure interferes with the proper rectifying action.

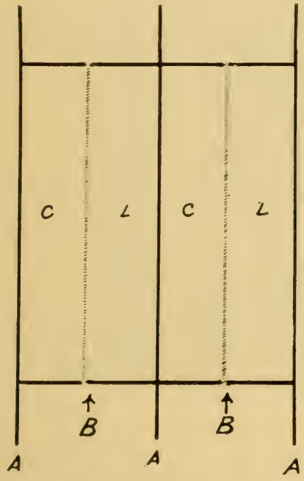

FIG. 74G.—C C are copper discs or washers; B B shows the copper oxide (or sulphide) coating; L L are lead discs or washers and AAA are metal "fins" to aid in heat radiation.

(53) In commercial form the stack rectifier consists of a number of lead and copper washers pressed together as pictured in Fig. 74E and diagramatically illustrated in Fig. 74G. In 74G CC represents copper washers coated on one side with copper oxide, LL lead washers used to make connection with the copper oxide, BB represent the copper-oxide coating, AAA heat-radiating fins. In radiating heat to the air, fins are highly efficient. In addition there is a fan, binding post and a protective casing.

(54 These rectifiers are not likely to require either repairs or replacements. In fact, they should be left entirely alone, except for careful and frequent inspection of the electric fan that is used for cooling. (55) A poor fan will soon cause overheating of the rectifier, which will injure it seriously. However, manufacturers of the projection lamp rectifier are now using a mercoid switch. The breeze created by the fan operates upon a flexible arm to keep the mercoid switch closed. If the fan stops, or slows down the mercoid switch opens automatically, stopping all current from flowing into the rectifier units. Approved, brushless, ball-bearing fan motors are used for this work.

Fig. 74H shows a stack rectifier that is widely used.

(56) The efficiency of stack rectifiers is comparable to the operating averages of other types of current

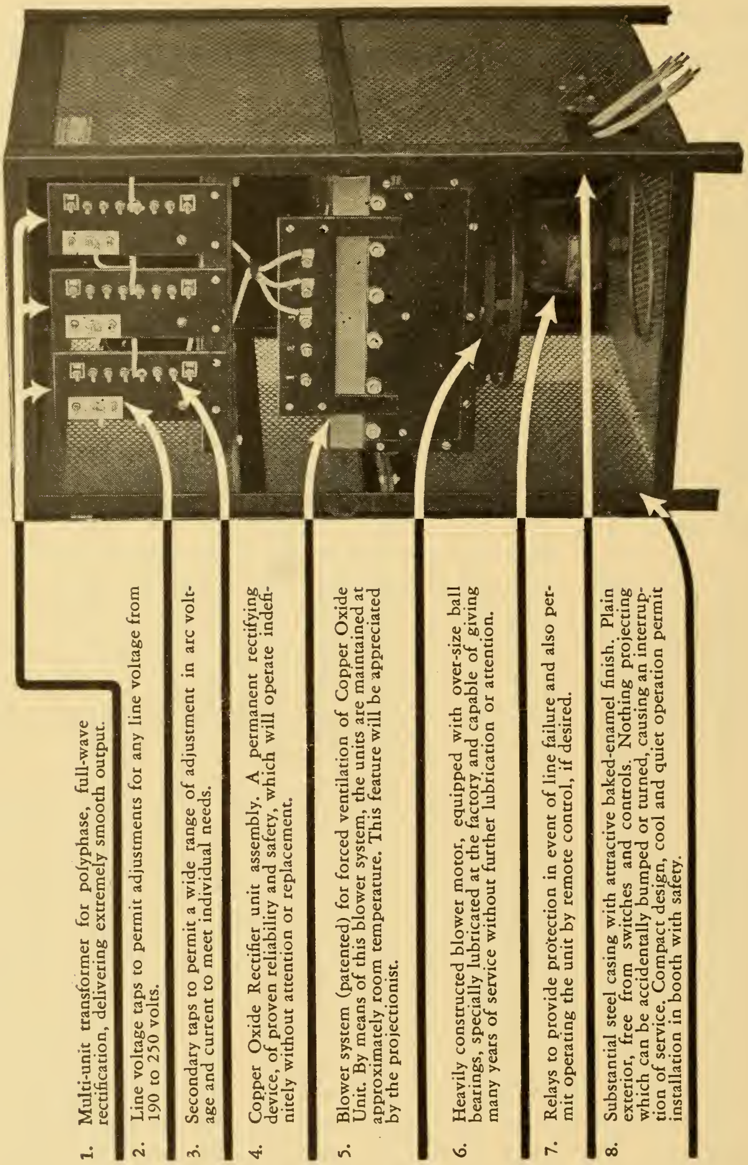

FIGURE 74H

rectifiers. Different amperages may be obtained from them. Their installation is simple. No special foundation is required. They do not have to be bolted down and require no lining up. They need no "warming up," but are ready as soon as the switch is closed.

(57) Substances other than copper oxide are sometimes used for the coating. Copper sulphide has been tried, and a number of combinations of metal and coating have been patented. Copper oxide remains the most effective for projection current rectifying purposes.

(58) At the present time copper-oxide rectifiers are made only for 3-phase current. They can be made in either single or 2-phase and doubtless will be if there is sufficient demand.

Fig. 74I is the circuit drawing of a three-phase, copper-oxide disc rectifier, essentially the same as that illustrated in Fig. 74H. Power supply to Fig. 74I is obtained from two separate sources, which are a three-phase, 220-volt a.c. line and a single-phase, 110-volt a.c. line. The purpose of using two separate sources is to make possible control of this rectifier by the same 110-volt a.c. switch that supplies power to the sound apparatus and to the projector motors. Through a relay built into Fig. 74I the same switch can be made to control the three-phase arc supply also, and hence to serve as a master switch for the entire projection room.

When this arrangement is followed the rectifier of 74I, which has no tubes to watch or change and needs practically no attention, can be installed in the generator room, the cellar, or any other convenient place, and switched on in the morning and off at night by means of the 110-volt master switch.

There are two 110-volt circuits in Fig. 74I. The first (from the input at the right of the drawing) merely runs through the fan motor, setting the fan in action as soon as the external master switch is closed. The second 110-volt circuit may be traced from the upper 110-volt wire to the mercoid switch shown just above the fan. This switch consists of a small glass tube, with two electrical contacts sealed into the glass, and a pool of mercury that closes the circuit between them when the glass tube is tipped to accumulate mercury in that location. When the tube is tipped the other way the mercury runs down to the other end, and the circuit opens. This switch is mounted on a suitable hinge, together with a light metal vane that is placed directly in the path of the breeze from the

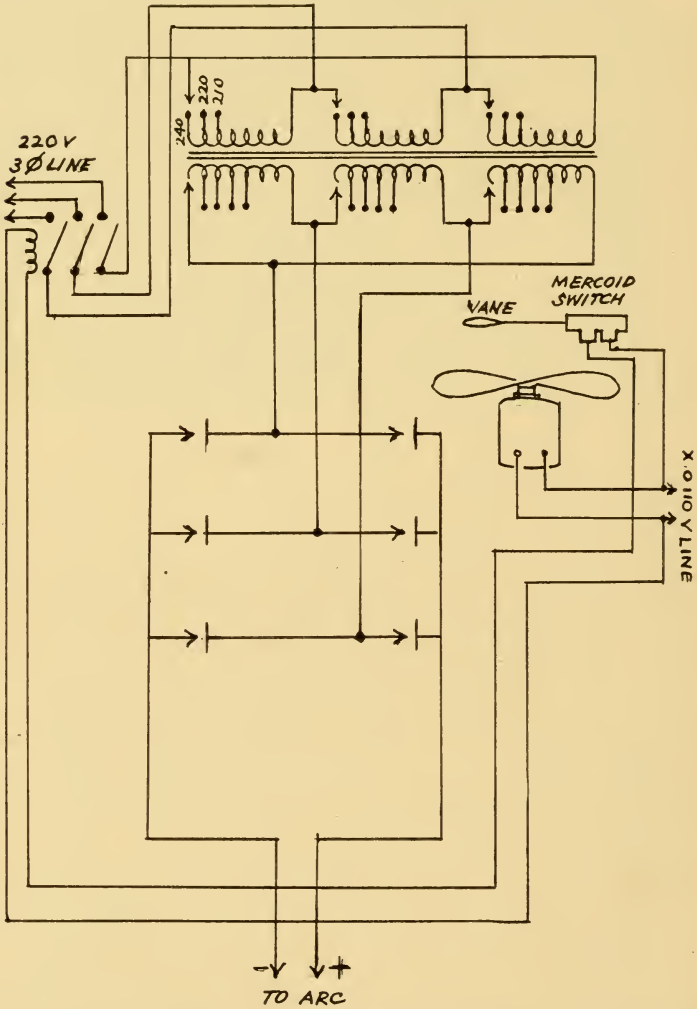

FIG. 741. Circuit drawing of a 3-phase, copper oxide disc rectifier. Should the blower stop for any reason the mercoid switch will act in cooperation with the magnetic switch to cut off the primary current and thus save the units.

fan. With the fan inoperative, the mercoid switch is open. When the external master switch is closed and starts the fan, the pressure of the breeze acting upon the light metal vane closes the 110-volt circuit through the mercoid switch.

The circuit continues down, across the bottom of the drawing and up to the magnet coil shown just to the left of the three-blade, three-phase input switch, and then back across the bottom of the drawing and out at the lower 110-volt wire.

Consequently, when the external 110-volt switch is closed, the sequence of operations is: the fan starts: the fan breeze closes the mercoid switch; power is supplied to the magnet of the three-phase switch, and that switch closes and supplies 3-phase power to the rectifier proper.

In addition to closing the mercoid switch, the breeze from the fan keeps the copper oxide stacks cool, and this is its chief purpose. Should the fan fail for any reason whatever, mechanical or electrical, or should the power of its breeze decline below the safety point, the mercoid switch will open, the three-phase switch magnet coil will no longer receive power, the three-phase switch will open, and the operation of the rectifier will stop until repairs are made.

This arrangement, while providing an invaluable precaution, makes the operation of the arc lamp supply entirely dependent upon a single electric fan, and consequently an ordinary electric fan is not used, but one especially designed for long life and unfailing operation, and far heavier in construction than an ordinary fan of the same rating. In practice these fans give no trouble, and copper-oxide rectifiers of this type are commonly installed in cellars and other remote places where they receive very little attention.

The input circuit to the rectifier proper is to the three primary windings of the power transformer, which are delta-connected, and tapped to provide proper arc current from either 210, 220 or 240 line volts. The design of the transformer core is such that excessive current cannot be drawn while striking the arc. The three secondaries are also delta-connected, and provided with "aging" taps, for this reason: The copper oxide units deliver somewhat more than their rated output during their first 3,000 hours of life. After that use, their output declines slightly, and thereafter remains constant through an indefinite future. Aging tests that have now been in progress for seven or eight years give no definite indication that copper oxide units ever wear out. The taps provided on the transformer secondaries allow readjustment of the transformer output to the copper oxide units when the period of aging is completed, and thereafter need no further adjustment.

The six rectifier stacks are drawn below the transformer secondaries.

Tracing the circuit of the left-hand secondary at the moment when its left-hand end is positive: that circuit runs down, right, down, right through the top right-hand stack, and down, left and down to the arc. The negative return from the arc is up, left, up to the middle left-hand stack, and up to the right-hand end of the same secondary. When the polarity in that secondary is reversed, the circuit from positive to negative is: down from the right-hand end and left through the middle right-hand stack, down, left and down to the arc: up, left and up to the top left-hand stack, through this and up to the left-hand end of the same secondary.

The circuits of the other two phases can be traced similarly, and it will be found that a full-wave rectifier is connected across each secondary of the transformer, the d.c. outputs being paralleled.

Double or "twin" copper-oxide rectifiers are also commercially available, similar to Fig. 74I except that the transformer has two separate sets of secondaries, each supplying its own independent set of six stack units. Each set of six stack units then supplies its own projector.

Such double rectifiers are sometimes provided with external switches, permitting operation of both projectors from either set of stacks, in the unlikely event of trouble with the other.

Installation—Operating Instructions

(59) Since excessive heat is injurious to the units,

copper oxide rectifiers should be placed in as cool a location as possible. A cool basement is excellent, inasmuch as these rectifiers require a minimum of attention.

(60) The output voltage should be checked occasionally during the aging period, and at reasonable intervals thereafter. The units should be inspected monthly for evidences of overheating, and to check the condition of the fan, and the freedom of motion of the mercoid switch vane.

Motor Generator Sets*

Before discussing motor-generator sets we believe it will be helpful to define certain terms and conditions which the projectionist encounters in his work almost daily.

Brush

(61) A plate of carbon forming a sliding electrical contact between the rotating commutator bars of a d. c. motor or generator (or between the contact ring of alternators) and the stationary wires of the outside circuit. Such brushes are of many varieties, each designed for a particular duty. The projectionist should study the composition and functioning of brushes, that he may be able to select proper brushes for the various motors and generators under his care.

Brush Loss

(62) Although the brush sets up resistance to the flow of current, the term "brush loss," for the most part, has reference to the loss at the sliding contact between the brush-end and the rotating surface of the commutator or contact ring. The loss may be low or it may be very high. A clean, non-sparking contact signifies a low brush loss. Rough, dirty surfaces will result in a high brush loss, especially if it is accompanied by sparking, as is usually the case. Insufficient pressure of the brushes on the commutator or contact ring also causes

*Only motor-generator sets used for projector light source current control are considered in these pages.

high brush loss, though too much brush pressure tends to wear both brush and metal surface unduly, and to cut grooves in the surface of the metal.

Brush Pressure

(63) Brush pressure refers to the pressure by which brushes are held to the contact surface—by means of a spring. It is considered in terms of the pressure exerted by each square inch of brush or contact surface. (64) The pressure must be just sufficient to insure good electrical contact when the surfaces are smooth and clean; it should never be less than 1¼ or more than 1½ pounds per square inch of contact surface. (65) Too much pressure means excessive brush wear; too little pressure induces sparking, roughening of the metal surface and a bad condition all around. (66) The pressure may be measured roughly by means of a small, accurate spring scale. (Test the scale for accuracy by weighing something previously weighed on a standard scale.) Attach it to the end of each brush finger by any convenient means, and note the pull required to just start the finger off the brush. Then calculate the surface of the brush in square inches (width of brush multiplied by the width of its contact surface) and adjust the pressure so that it will not be less than 1¼ or more than 1½ pounds per square inch.

Brush Rocker or "Yoke"

(67) This is a metallic yoke to which the brush holders are attached and held by it in proper position. This "yoke" may be moved (rocked) backward or forward to change the position of the brushes circumferentially with relation to the commutator. This brush position is highly important. Once located at the point of least possible sparking, means are provided to lock the yoke into position.

Compound-wound Generator

(68) Upon the field magnet of this machine are wound two sets of coils, one of which is connected in series and

the other in parallel with the armature, and therefore with the outside circuit. Such winding is intended to provide better voltage regulation on constant voltage systems than is possible with shunt-wound machines. Compound wound machines have some of the characteristics of both the shunt and the series wound generator.

Compound Wound Motor

(69) Compound field magnet motor winding tends to secure unvarying speed under a variable load.

Commutator

(70) A series of copper bars mounted side by side around the circumference of an armature shaft at one end of the armature windings. These bars are insulated from each other and the armature windings are so connected to them that although they receive a. c. from the armature windings, they deliver d. c. to the outside circuit.

Commutator Bar

A single copper bar, numbers of which together make up a commutator.

Commutator Flats

(71) Low spots on a commutator, where the brushes have worn the surface unevenly.

Commutator Lug

(72) An extension on the inner end of the commutator bars to which leads from the armature windings are connected both mechanically and by solder.

Field Coil

Wire wound upon the field magnets or magnet of a generator, dynamo or motor.

Magnetic Field

Space occupied by magnetic lines of force.

Field Poles

Poles of a magnet forming a magnetic field. As applied to motors and dynamos, they are the poles that form the field in which the armature of the dynamo or motor rotates.

Field Rheostat

A rheostatic resistance, usually adjustable, employed to control the flow of current through the field coil or coils of a dynamo motor.

Generator

A machine which transforms mechanical power into electrical power. Such machines are commonly termed "dynamos" if they produce d. c.; "alternators" if their output is a. c.

Magnet

In the ordinary acceptance of the term, it is a body of iron charged with magnetism and generating or having power to generate a magnetic field. It may be a "permanent" magnet (a polarized electro magnet), in which case the magnetic field is always present; it becomes an electro-magnet only when excited by the passage of current through wires wound around it. Permanent magnets usually are of steel; electro-magnets are generally of soft iron. Magnets, permanent or otherwise, may be made more powerful by passing current through coils of wire wound around them.

Magnet Coil

A coil composed of insulated wire wound upon an electro-magnet over which current is passed to "excite" it to greater magnetive power. Also called a "field coil."

Magnet Core

A bar of iron or a lamination of insulated, thin iron plates around which the magnet coil is wound.

Magnetic Density

The number of lines of magnetic force passing through a magnetic field per unit area of cross section. Every magnetic field has greater density near the poles of the magnet, dropping off rapidly as the distance from the poles is increased.

Magnetic Field

Any space through which magnetic lines of force pass. It is a term particularly applied to the space immediately surrounding the poles of a magnet. The phase is strongest near the poles, decreasing rapidly with distance and finally fading out entirely.

Magnetic Flux

Average density of a magnetic field per unit area multiplied by its area. It is really the total strength of a magnetic field or magnetic density.

Parallel Connection

(73) Two or more generators of equal voltage so connected that the positive of all connect to one positive conductor and the negative of all to one negative. The result is a voltage equal to the voltage of any one of the machines, but a current flow (amperage) equal to the combined output of them all.

Period

The time required to perform a complete cycle of periodic motion or action.

Polyphase Current

(74) This is represented by two or more alternating currents of like period, joined to operate as a single power supply with fixed spacing of their phase. Such currents usually are produced by separate sets of coils wound upon the armature of an a. c. generator, each coil a little in advance of the other. Also such currents may be produced by one or more single-phase alternators

coupled together so that there is a continuously fixed phase spacing of their output.

Series-Connected Dynamos

(75) Two or more dynamos connected in series will produce current flow (amperage) equal only to the capacity or output of any one of them, but the resultant voltage will be equal to the combined voltage of them all.* Thus, two 110 volt, 70 amperage machines in series would charge the circuit with 220 volts and supply a maximum of 70 amperes.

Series Wound Dynamo

(76) The winding consists of a relatively small number of turns of heavy, insulated wire wound upon the field magnets of the machine—this being in series with the armature, so that the entire armature output passes through the coil.

Shunt

(77) As applied to an electric circuit it is a branch conductor which joins the main circuit at each end. It forms a parallel path by means of which the current flow is divided, the portion flowing through the shunt serving, presumably, some special purpose.

Shunt Circuit

This is the same as "shunt."

Shunt Wound Field

(78) A shunt dynamo having a field in the form of a circuit that forms a shunt to the external circuit. Such shunt field-winding consists of many turns of a rather small wire. It is regulated so that only a small portion of the armature current passes through the shunt field.

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*Power output is measured in watts, which is equal to volts times amperes. It then follows that increase in either amperage or volts, or both, increases power.

Shunt Motor

(79) A motor in which the armature windings are connected in parallel with the field magnet windings.

Squirrel Cage Winding

(80) An armature winding often employed in induction motor rotors. It is constructed of copper bars located in slots near the surface of the core, all bars being connected to a short-circuiting copper ring at each end.

Shunt Wound Dynamo

(81) A shunt wound dynamo is one having a field winding of many turns of a relatively small wire connected in parallel with, or as a shunt to, the outside circuit. At the same time it is connected to the brushes of the machine in a manner to cause a portion of the current to energize and maintain its field.

Synchronous Motor

(82) An a. c. motor that must be brought up to full speed by applying a split-phase or other current before it is connected to the main power circuit. To all intents and purposes it is an a. c. generator run as a motor and in exact phase step with the current of the circuit from which it takes its power.

Synchronous Polyphase Motor

(83) A polyphase motor with a period and phase identical with that of the circuit from which it takes power.

Undercut

(84) As applied to insulation in motor generator sets, this term refers to cutting the insulation between commutator bars down below the level of their surface.

Utility of Motor Generator Sets

(85) To supply current to a projector light sources, the motor generator set is a d. c. dynamo of low voltage

to permit the use of sufficient ballast resistance to stabilize the light source to burn steadily. Without such resistance in series an arc will not burn steadily; also, lack of sufficient resistance will cause an immediate dead short-circuit as soon as the carbons are brought into contact to strike an arc. By reduction of voltage the waste in "breaking down" the line voltage to arc voltage is reduced to the minimum consistent with good operation.

(86) To drive the dynamo there is a motor, mounted on the same "bed plate" (often referred to as a "sub-base"). This motor may be either a. c. or d. c., but usually is a. c., and for two reasons: first, in almost all localities the supply lines are charged with a. c., usually 60 cycles at 110 volts, or 110-220 volts if it is a 3-wire system. (87) Secondly, as will be explained, it is unprofitable to install a motor generator set where d. c. power is available at 110 volts, as it generally is where d. c. is available from power lines at all.

(88) Where the power lines supply a. c. there is a double purpose served by using a motor generator set: first, it reduces the line voltage to a point about 25 volts above the voltage required at the light source, thus reducing the waste in rheostative resistance to a minimum; secondly, it permits the taking of a. c. power from the line to drive a d. c. dynamo. It thus accomplishes both voltage reduction and current rectification.

Where d. c. is available from the power lines, only one purpose is served by installing a motor generator set, the reduction of voltage. Considering that a certain amount of ballast resistance is necessary and that motor generator sets at best have an efficiency rating of only about 70 percent (including the loss through ballast resistance) and considering also that unless they are expertly and carefully handled they may drop below that figure, it is readily understandable that the saving is too small to justify installation of a motor generator when 110 volts d. c. is available.

We therefore do not advise the installation of a motor-generator set where 110 volt d. c. is available.

If the available d. c. voltage is 220, then an installation will be justified because it is too costly to absorb all the wattage (represented by the amperage multiplied by the difference between the line (220) and arc voltages) through rheostatic resistance. If, for example, the amperage is 75, the line voltage 220 and the arc voltage 55, the waste would be 12,375 watts (220—55 = 165 × 75), or more than 12¼ kilowatts. But all other factors being normal, if the line voltage is only 110, then the waste would only be 4,125 watts (110 — 55 = 55 × 75), or 4¼ K.W., were rheostats used.

Remembering that motor generator sets, under average conditions, are only about 70 percent efficient (the general average is probably even lower), it is seen the difference in their favor is too small to justify their use where the power supply delivers 110 volts d. c.

(89) As a matter of fact motor generators, as a rule, possess an efficiency average of about 65 percent—that is, for every 100 watts taken from the power line, only 65 will be available at the light source. A well designed, well constructed set will have an efficiency of approximately 70 percent. But often because motor generators are seldom kept in perfect condition and adjustment, their actual efficiency drops until it is somewhere between 45 and 70. Very much depends upon the intelligent care given them by the man or men in charge.

(90) Both motor and generator should be mounted on one bed plate of metal and bolted solidly down. This insures a permanently perfect alignment of the motor and generator shaft—an essential quality since the shafts are rigidly connected, usually by means of a flanged, bolted, unyielding iron coupling.

(91) The generator may be either of the parallel type, which means a machine that maintains constant voltage under variations in current output, or it may be of the series type which, within the limits of its capacity, automatically increases or decreases its voltage as current flow (load) is raised or lowered. Generators employed in projection should be capable, while supplying one light source, of automatically increasing its voltage

enough to maintain the amperage without change for a limited period every time a second light source is cut into operation in series with the first, thus doubling the load. The parallel type generator is a "constant voltage" and the series type a "constant current" machine.

(92) The design of motors and generators has been greatly altered and improved since motion pictures first came into use. Since their participation in projection, motor generators have undergone many marked alterations as the requirements of the projection room changed.

In the early days of projection, the arc light source was served through rheostatic resistance from both a. c. and d. c. supply lines but it was recognized from the first as a wasteful procedure. Various forms of choke coil were substituted for resistance, because they were far more economical than the rheostat, though more or less erratic in operation, and the light obtained from current through a choke coil had a very harsh, "blue" tint that was not pleasing.

Finally, along about 1907 J. C. Hallberg, a motion picture supply dealer, developed a low-voltage transformer especially designed for use with projection arcs. It yielded a definite saving over rheostatic resistance and delivered a decidedly better projection light source current than the choke coil. Since its cost was reasonable it was very generally adopted for use with a. c. projection arcs. This transformer, known as the "Hallberg Economizer," was the first important step in the control of current for projection light sources.

The superiority of the d. c. arc as a projection light source was so obvious, that soon there was a widespread demand for a practical means of converting a. c. into d. c., which brought about the development of the mercury arc rectifier, the rotary converter, the motor generator set and other devices, including the electrolytic rectifier. In the beginning all these machines were crude, but they were rapidly improved, as competition became keen to capture the waiting theatre market.

The motor-generator was recognized as a superior machine because it was very flexible in the amount of load it was able to carry and, if properly cared for, unlikely to give trouble of any sort for a long time.

(93) The series type generator offered distinct advantages when current requirements were high and fairly constant. Today amperage needs fluctuate so widely that the series type is no longer in favor; the demand is for the multiple type generator, because it has a fairly wide range of current (amperage) output and is moderately economical in operation. Incidentally, among multiple action generators the horizontal type is most widely used because it is held to possess superior advantages in certain respects.

Ballast Resistance and Generators

(94) The term "ballast resistance" as used here refers to rheostats that form a part of motor-generator sets, being used to absorb the difference between the generator and arc voltage. Their purpose will be fully explained in the following pages.

(95) In the parallel type generator there is a very definite relationship between the arc length and current flow on the one hand, and rheostat ballast resistance capacity and arc voltage on the other. The correct voltage across a low intensity (reflector type) arc is between 50 and 55 volts. Across the standard (old style) d. c. arc it varies between 55 and 60. Across the straight high intensity arc it is from 65 to 70 volts.

(96) If the generator operates at 80 volts, supplying a 55 volt arc, it follows ballast resistance exists to absorb or "break down" (80-55) 25 volts, dissipating that amount of power in the form of heat that is absorbed by the surrounding atmosphere. It must be able to do this without over-heating the grids or wire coils. (97) In other words the ballast resistance must have sufficient capacity to do its job without being overloaded; and the greater the amount of voltage it must absorb the greater must be its capacity, remembering always that the break-down represents wattage and wattage represents power that must be paid for.

Another type of error lies in using too much resistance for a given amount of work. Instances have been found where a projectionist was attempting to operate a high intensity arc off an 80-volt generator, using a ballast resistance designed to take care of a 25-volt drop. In such a case, if a 65-volt arc is maintained (the lowest voltage practicable with a high intensity arc), there is a 25-volt resistance and only a 15-volt drop, the result being that the generator cannot force through sufficient current. The remedy is either a higher generator voltage or a ballast resistance suited to the work.

The foregoing is designed to emphasize the importance of maintaining proper relationship between generator voltage and the ballast resistance.

Parallel Generator Equalizers

(98) Between two parallel compound-wound generators it is necessary to have a special connection called an equalizer. The reason for this is easily understood. To secure constant potential performance compounding is necessary, which varies in different designs and sizes of generators. In fact it may vary somewhat between two generators of identical design. Even changes which involve alteration in operating voltage and (or) brush position may cause variations.

Presuming two generators to be set for parallel operation their compounding will be balanced by means of a proper equalizer (99) consisting of a connection of a heavy copper bar known as a bus bar between their series coils. This prevents the current in the series fields from differing to any extent, regardless of how much the variation may be in their armature currents.

(100) If, however, one of the generators is started and warmed up to normal operating temperature and the second generator, while still cold, is cut immediately into the circuit with its voltage adjusted to match that of the first machine, what happens?

As the second generator warms up its voltage will drop, compelling the first generator to assume a portion of its load. The field regulation of the second generator must then be adjusted by hand to make up the difference, whereupon the load thereafter will be automatically equalized between the two.

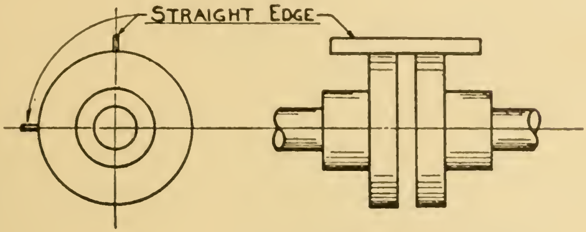

FIGURE 75

Usually two generators will parallel very nicely if connected through a properly designed equalizer, though they may require an adjustment of the field regulators each time at starting to equalize the load.

(101) In motor generator sets not having both motor and generator mounted on one solid base, it is very important that the alignment of the motor and generator shafts (assuming them to be connected by flanges as shown in Fig. 75) be carefully tested. Unless these shafts are in perfect alignment there will be vibration and perhaps noise.

The test should be made before the flanges are bolted together. (102) This may be done by laying a steel straight-edge across the face of the flanges, as shown in Fig. 75. In case the faces of the flanges are not machined flat, then a longer steel straightedge, such as a carpenter's steel square may be laid upon the coupling and aligned with one shaft by caliper measurement and if the alignment is correct the measurement from the other shaft to the opposite end of the straightedge will be the same. This must be done both on top and on the side. Be sure to have the straightedge in perfect alignment with the shaft lengthwise when making the test.

Another though less accurate test is to bolt the flanges tightly together. Then unbolt them and if the flanges surfaces remain in contact all the way around the alignment is correct.

Careful Attention Essential

(103) A motor generator must have careful, intelligent attention in order to work with reasonable efficiency. Many motor generator sets that should work at sixty-five to seventy per cent in efficiency are, because of careless or unintelligent care, working at fifty or fifty-five. Many drop even below that.

(104) To work at maximum efficiency a motor or generator or a motor generator set must (a) be kept clean throughout. (b) It must have the exact size and kind of brushes indicated for the service. (c) Its brushes must make good electrical contact with the commutator over their entire contact surfaces. (d) Brushes must contact the commutator with between 1.25 and 1.50 pounds of pressure per square inch of contact surface. Too little pressure gives poor contact; too much pressure induces sparking and tends to wear grooves in the commutator surface. (e) The brushes must fit in their holders as snugly as possible without binding or sticking. A brush that is loose in its holder will "chatter" and move about, making poor electrical contact; one that is too tight may stick in its holder and set up very bad sparking. (f) The commutator surface must be kept clean. It should present a smooth, glazed surface, brown in appearance. (g) The mica insulation between the commutator bars must be kept undercut (its surface below the surface of the commutator) from 1/32nd to 3/64th of an inch. The mica must never be allowed to be even with or project above the surface of the commutator. (h) The commutator bar connections (soldered) must be perfect. (i) There must be no sparking, or at best a negligible amount. (j) The commutator bars must not be permitted to wear down unevenly, or to become so thin that they are unable to carry the current without heating. (k) All bearings must be lubricated with oil or grease of the grade recommended by the manufacturer. (m) All wires, switches, etc., must be large enough to carry the load without undue resistance. (n) Allow a slight end-play of the armature in sleeve-bearing horizontal type generators as this aids to prevent commutator grooving.

Effect of Resistance

(105) One very important item in operating efficiency is that there shall be but the minimum possible ballast resistance interposed in the line, since all resistance above what is strictly necessary to steady the arc is wasted. Unfortunately, in the types of arcs in use at present the stability of the light source depends upon a certain amount of resistance in series with it. This is termed "ballast resistance." If it is too little the arc will be very unsteady and give poor screen illumination.

(106) Experience shows that the steadiness of a projection arc is assured only when there is sufficient ballast resistance to avoid the excessive variation in current flow that comes from irregularities in the arc feed and the consequent arc length and the variations in carbon resistance. (107) The voltage of the generator of a motor generator set above that of the arc is usually not less than 15 volts and often as much as 30.

(108) The skillful projectionist who keeps his arc feed mechanism working perfectly will secure satisfactory results with less ballast resistance.

Oil and Dust

Keep the motor-generator set scrupulously clean. (109) Oil acts as an insulator, but it will soften the armature insulation, collect dust, grit and metallic particles, and these, if permitted to remain, may in time produce a short circuit with serious damage to the equipment.

Do not permit dust to accumulate around the armature and pole pieces. (110) It is especially important that all dust be blown out from between the pole pieces and armature once each week in all-day houses, and once every two weeks in two-a-day theatres, because the magnetism of the pole pieces gradually collects bits of metal dust from the air and thus impairs the efficiency of operation. Managers should provide a hand bellows of ample size for this purpose.

Worn Bearings

(111) Many motors and generators have but little

clearance between armature and pole pieces. Naturally any wear in the bearings will reduce the clearance at the bottom and increase it at the top, the shorter gap below becoming a danger point. Projectionists should therefore check up on bearing wear at frequent periods—at least every thirty days. This does not mean that a properly lubricated bearing will wear appreciably in thirty days; it is simply a precaution. If the bearing should fail because of lack of oil distribution trouble may come very quickly.

(112) Ball bearings usually proclaim that they are worn by becoming exceedingly noisy. Sleeve bearings give no warning except through heat.

There is no one best way to check up on bearing wear. A good mechanic will do it almost intuitively. A strip of hard cardboard, about an inch wide and a foot long may be slipped between a pole and the armature. Then, grasping both ends, it can be worked gradually around until it has passed between all poles and the armature surface, thus making sure that no friction exists between the two elements. Because of the dirt that settles on the pole face it is sometimes impossible to see through the air gap; also the gap below the armature may seem smaller than the gap above because more dirt is gathered on the faces of the lower poles. The cardboard removes some of the accumulated dust.

(113) A set of gauges or "feelers" may be purchased from automobile supply dealers. This is a series of thin steel strips varying usually from .002-in. to .010 or .015-inc. in thickness. They are held together in a frame like the blades of a jack-knife and can be laid together in any desired combination so that by building up to any desired thickness and inserting it into the gap, the width of the gap can be tested accurately.

(114) An equally efficient check is to pry with a bar inserted under some exposed part of the armature shaft. Pressure will make the armature rise in the bearing if the bearing is worn. The "looseness" of the bearing indicates the wear.

(115) Lubrication of sleeve bearings usually is accomplished by means of oil wells. Under each shaft

bearing is a depression in the casting as shown at the left in Fig. 76 which reveals the detail of a ball-race at the right. Over each journal there is a metal ring, fitted into a slot provided for it in the bearing, as shown at the left in Fig. 76. The ring extends down into the depression, which is known as the "oil well." As the shaft revolves, the ring rotates also and obviously will carry oil up to the top of the shaft, thus accomplishing lubrication. The oil well should be filled with proper oil and refilled with fresh oil whenever a test shows the oil to be getting low in lubricating power.

(116) It is impossible to say how often the oil should be replaced, as its useful life depends upon many factors.

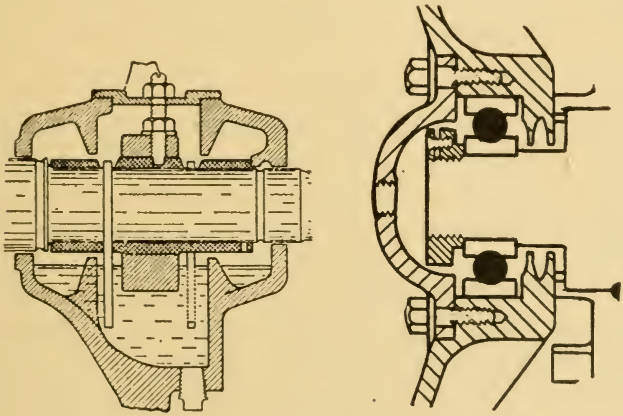

FIGURE 76

such as the hours of operation per day, the bearing and room temperature, the quality of the oil used, peripheral speed, air condition and so on. Motors are known to run for long periods without a change of oil. On the other hand dust may settle on a neglected bearing, drawing out the oil by capillary action in a few weeks' time. It is best to look at the oil whenever the machine is inspected. If it is clean and at the proper level it needs no attention.

(117) A proper oil is a highly important item. The journal and bearing will wear down rapidly with poor quality lubrication or one that is unsuited to the work. To save half a dollar on a gallon of oil that brings

about ten dollars worth of unnecessary damage to machinery is exceedingly false economy.

It is best to ask the manufacturer to recommend a lubricant and to follow his recommendation even though he may name an oil he himself supplies. His reputation requires that his machine perform well, and he is extremely unlikely to suggest anything but what is proper.

Ball Bearing Lubrication

(118) Be exceptionally careful about the lubricant for ball bearings. It must be wholly free from acid because acid will roughen quickly the polished surface of the balls and their races. Grease that contains animal fat is acidic and should not be used. Here, too, the manufacturer's advice should be followed implicitly.

Installation Suggestions

(119) Immediately upon receipt of a new motor-generator set examine its name plate, making sure that the voltage, phase and frequency of the motor and amperage capacity of the generator are what are required for your particular purposes.

Sometimes, after all the work of installation has been completed one of those factors has been found to be wrong, whereupon the whole set had to be removed and another installed. (120) Small two or three-phase motors, say up to and including 5 H.P. capacity, usually may be connected with the line merely by closing a switch. For larger motors a "compensator" or variable resistance starter is required.

(121) All wires must be large enough to carry the current without developing unnecessary resistance (voltage drop), which of course means waste. (122) It is a mistake to consider the installation satisfactory if the wires merely carry the maximum current permitted by the Underwriters. Underwriters' wire capacity restrictions indicate safety for wires and insulation but offer no guarantee of real economy in operation. As a matter of fact, any wire working at maximum Underwriters' capacity will offer enough resistance to show considerable

waste of power wherever current costs are high. It is much more economical and more efficient to install wires larger than the Underwriters call for. The saving on current consumption will be much greater than the initial cost of the larger wires.

(123) Calculate (see page 66) the difference in cost per working hour between, for example, a No. 6 wire loaded to capacity, and a No. 4 wire conveying the same amperage. Multiply this by the estimated number of hours of operation per year. You will be surprised at the saving particularly if both current cost and amperage used are high.

(124) In installing the main projection room circuit and the circuits feeding the projectors, spots, effect projectors and stereopticons, be sure to make ample allowance for possible future increases in current consumption. You may think this an unnecessary suggestion but the cost is little and the precaution is wise. It is both expensive and troublesome to be forced later to pull out all the wires and install larger ones, or to run an auxiliary circuit. In any event install conduit large enough to accommodate larger wires, should they become necessary.

(125) The voltage drop of any wire circuit may be ascertained by multiplying the one-way length of the circuit by 21 feet; multiply the product by the amperes and dividing the result by the circular mil area of the wire. This will give you the voltage drop.

(126) Before purchasing a motor-generator set for the projector arc supply, make sure that the generator performance curve is flat (constant voltage over the amperage range of the generator) at the level at which the set is to operate.

Installation

(127) It is extremely unwise to locate a motor-generator set in a basement or any place far removed from the projection room. A good set is quiet enough to be installed in a room immediately adjacent to the projection room, provided it is placed on a support or foundation sufficiently solid to avoid vibration. Furthermore the set

should sit immediately on either rubber, cork or springs, which will absorb any slight vibration the machine may create.

(128) Located thus the motor-generator set will be under the constant observation and care of the projectionist which it cannot have when removed far from the projection room. Moreover, basements are often damp and sometimes flooded—both of which damage the equipment.

Spacing

(129) Be sure to leave clear space on every side of the set. Men must have room to work around a set if it is to be well taken care of. Install a drop light (preferably a reel light) on a long cord so that the projectionist may be able to illuminate any part of the machine without difficulty.

A thick layer of cork or rubber absorbs vibration for a time, but with the passage of time these substances lose a part if not all of their resiliency. (130) Were we considering the installation of a motor-generator set in a theatre of our own, we would set it on coil springs not less than six inches long, and of such capacity that four of them, one under each corner, would carry the weight with no more than one inch depression. Coil spring supports are not expensive. Any responsible spring manufacturer will supply them. Order four springs that will carry the weight of the set and he will guarantee sufficient resiliency to absorb all vibration.

It is necessary to make a strong concrete frame of proper depth and size and sufficiently massive, with a half-inch bolt embedded head down near each corner and protruding about one and one-half inches above the surface. The springs themselves should consist of a spiral of from four to five inches diameter at one end, tapering to about two and one-half inches at the other, the extreme large diameter of the steel being turned in to the axis of the spring and curled to take a half-inch bolt readily.

The smaller end of the spring is then bolted to the bottom of a wooden frame on which the motor-generator set is to rest, or directly to the bottom of the cast iron or steel base of the set. The larger ends of the springs are attached to the ends of the imbedded bolts. The taper of these springs gives the assembly more stability than would be had were they cylindrical, without at all decreasing their action. With such an arrangement (which sounds complicated but is very simple and low in price) we will guarantee despite the fears of many exhibitors that neither vibration or sound will be communicated to the building.

If the manufacturer of the set, or the contractor who is to install it, is a responsible factor, and desires to support the set by some other method, and is will to guarantee, in writing, against noise or vibration, such guarantee should be accepted.

Brushes

(131) Points of importance with relation to brushes are: (a) they must fit their holders snugly, but not so tight they will stick in their holders, (b) they must relate to the machine in size and be able to carry its maximum current without heating; (c) when new brushes are installed they must be fitted accurately to the commutator curvature. (132) This last may be done by laying No. ½ sandpaper (never emery cloth or emery paper) on the commutator, the ends of the brushes resting on the sand side at normal brush pressure. Draw the paper forward in the direction of the commutator rotation, and repeat the operation until the brush ends fit the curvature perfectly.

If the brushes fit their holder snugly the job may be done more easily and quickly by drawing the paper back and forth until the brush ends are worn almost to the proper curvature. At the finish it is best to draw the paper a few times in the direction of the commutator rotation only. It is a tedious job, but only needs to be done at long intervals.

Do not experiment with brushes. Use only those recommended by the manufacturer of the set.

The Commutator

The careful projectionist will pay close attention to the generator commutator. He will study its requirements and if something seems wrong will attend to it immediately. Sparking cannot always be eliminated entirely, especially if the machine is working close to capacity, but it should be reduced as far as possible. The instructions that follow are of great help.

(133) When there is little or no sparking and the surface is smooth, glazed and of a dark brown color it is the best evidence that the commutator is in the finest possible condition. If the condition is good there will probably be a slight squeak from the brushes when the armature is rotated slowly, though its absence does not necessarily indicate that anything is wrong.

Yoke Mark

(134) On all modern types of motor-generator sets the correct setting of the brush yoke is indicated by a mark on the yoke and another on the frame. These should be exactly opposite each other. This setting does not contemplate a continuous overload or underload. If that is the case the brushes may need advancing or retarding.

To Test Brush Pressure

(135) An experienced man can test brush pressure with sufficient accuracy by raising the brush finger or spring. If the commutator has little or no sparking and the proper glaze, it is best not to touch it at all. For the brushes usually found on a commutator used for dynamos of this type a pressure of from one and one-quarter to one and one-half pounds per square inch of brush surface is approximately correct. A small spring balance will measure such a pull quite accurately. This may be hooked to the brush holder finger or spring and the latter raised just out of contact.

(136) If at this point—when the finger is worked up and down by raising and lowering the scale—it is found that there is a wide difference in the scale of reading,

it shows that the brush finger is too tight and the chances are that a good cleaning is in order. The purchase price of the scale is fully justified by the discovery of an undesirable condition even in a single brush holder.

If the brush is, for example one and one-half inch wide by three-eighths of an inch thick its contact area is roughly nine-sixteenths of a square inch, so that the balance reading should be fourteen ounces.

(137) Width times thickness will serve for calculating contact surface. The curvature of the contact face makes some slight difference, but not enough to affect results appreciably.

(138) A fresh, new rubber band with a piece of string at each end, previously calibrated as to stretch by lifting, say a pound, gives excellent results. The elongation of the rubber when raising the brush holder finger can readily be measured and is almost exactly proportional to the weight raised. In the example already cited we should expect fourteen ounces to stretch the rubber seven-eighths of an inch if the pound weight elongated it one inch. Or exact results may be had by first calculating the exact pressure the brush should have and then raising an equal weight (measured on a reliable scale) with the rubber, noting the exact amount of stretch.

Care of Commutator

Much depends upon the care the commutator receives.

(139) Unless the commutator is in good condition you will have sparking, which operates immediately to roughen and "pit" the commutator surface, thus making the condition progressively worse.

Cleanliness

The commutator must be kept clean and smooth.

(140) Aside from a daily endwise brushing to remove dust and other deposits from the undercut slot between the communtator bars, there should be little need for cleaning unless too much lubrication, or lubrication of the wrong kind has been applied, or the brushes contain too much paraffin.

(141) At least once each week the commutator should be brushed vigorously *lengthwise,* using a brush with bristles as stiff as may be without danger of injuring the surface. This is to remove from the undercut grooves between commutator bars any dust or foreign substance that may have lodged there. Much of the dust is carbon scraped from the brushes and copper worn from the copper bars. This worn copper quickly becomes a conductor.

Sandpapering

(142) In the event it becomes necessary, for any reason, to clean the commutator surface right down to the copper, use No. 00 sandpaper. Do not use anything coarser than No. 00 and under no circumstances use emery paper or emery cloth. Remove all brushes and, having started the motor (we are still considering motor-generators), hold the sandpaper against the commutator, without exerting too much pressure, until the copper shows clean and bright all over the surface.

(143) Stop the motor and give the commutator a vigorous brushing endwise. Next whittle a hardwood stick until its point will just fit into the undercut between commutator bars. Draw this through each one of the undercut slots to dislodge any copper bits that may have been drawn either across from one bar to another or down into the groove. Then brush endwise again vigorously.

(144) There are "commutator stones" on the market, which are rectangular bricks of fineness or coarseness to suit any "dressing" job.

The stone is held against the rotating commutator, and its surface wears down readily to fit the commutator curvature, in the meantime cutting freely. Unless the brushes are raised, they too will partake in this rapid wear-away-spree. In fact one way of fitting the brush ends to the commutator curvature is to let them rest in their natural position on the commutator and operate with a rather fine grade of commutator stone. The fit thus secured is perfect.

(145) After the stoning is finished, brush vigorously endwise to remove all grit and bits of copper from between the bars. Next, hold against the rotating commutator the lubricating pad which we shall presently tell you how to make. Then adjust the brushes and the commutator "dressing" is done.

Commutator Lubricating Pad

(146) To make this pad proceed as follows: From a medium-weight canvas cut a piece about six inches square and fold it so that it forms a pad 6 inches long by two inches wide. Dampen and press down, so it will stay folded.

Open the pad and along the center section of the inside of the pad, apply a light coat of ordinary vaseline. Refold the pad and lay it aside for a day in a warm place, to give the vaseline time to soak through the fabric. After this the pad should be kept in a closed box where it will be free from dust and dirt. The pad may be recoated with vaseline from time to time whenever it requires it.

By holding it against the commutator for a few seconds the commutator will receive all the lubrication it requires. If soft brushes are used apply no lubrication, as they contain sufficient paraffin for the purpose.

Commutator Conditions

Reduce sparking to an absolute minimum. (147) There should be little or none unless the machine is overloaded. If there is sparking and the machine is not overloaded, proceed at once to ascertain its cause.

(148) The easily discoverable causes are as follows: brushes improperly set; wrong brush pressure; poor brush contact; high commutator bar; improper brushes purchased for replacement; commutator out of round; commutator dirty; high mica.

Make sure that combined oil and carbon dust has not formed a short between the bars or formed a spot of semi-insulation on the commutator face. Be sure the commutator has no high bars and that it is perfectly round—either of these faults can be tested for easily.

(149) High bars may be detected ordinarily by a slight clicking sound when the machine is run at moderate speed, which can be accomplished without load by manipulation of the switch. There can be also a low bar or bars, in which case the brush would ride inward slightly as the armature is rotated slowly by hand. If the commutator is out of round, that fact may be made evident by rotating the armature slowly by hand, watching the brushes closely for an up and down movement in their holders.

(150) Often a very slight motion of the brushes up and down in the holder means nothing. It is sometimes impossible to get them to ride without some such slight motion. Commutators are turned originally on lathe centers, but in the generator its shaft revolves on bearings. The shaft center may be out of true with the journal a fraction of a thousandth of an inch, or the shaft may be slightly sprung. Perfection here is seldom reached. It will be unwise for anyone except the most experienced machinist to attempt to remedy such faults. In such cases the business of the projectionist is only to detect and report them.

(151) Test for "out-of-round" by resting some blunt pointed tool on a solid support, its face just in contact with the commutator, and rotate the armature slowly by hand, noting whether or not the contact is constant through one complete rotation.

Points that Need Watching

(152) Be sure no bit of copper has dragged across from one commutator bar to another. In that event a ring of light will appear, seemingly entirely around the commutator. Remove the trouble-making copper.

Make sure that the brushes all fit properly in their holders and that the holders are free from all accumulations of dust and dirt.

Be sure, if the set is one in which the armature lies horizontally and is not ball bearing type, that the armature has endwise movement (called "float") of at least three-sixteenths of an inch. This is quite important since it helps to prevent the brushes from cutting grooves in the copper. To have "float" it is essential that the armature rest almost in exact horizontal position. See that this is the condition when the equipment is installed.

The insulation between the commutator bars must be kept undercut to the proper depth.

The brush yoke must be set at exactly the position indicated by the mark, which should be present on both the generator frame and yoke. Any error in the yoke set in a normally loaded machine will cause brush sparking and a decrease in efficiency.

Be sure that there is some protection over the commutator to keep things from dropping upon it. This does not mean simply a screen such as the manufacturer furnishes as a guard against accidents. Cases have occured where the commutator was ruined and the winding burned out as a result of pieces of plaster dropping from a wall overhanging the machine. There should be a solid baffle of metal, or its equivalent, not too far above the commutator surface.

Sticking Brushes

(153) Brushes often stick in their holder when they fit too snugly or bits of dirt and grease work their way in between the brush and the holder or the brush itself is not true on its surfaces. The last is an unlikely fault, but is sometimes found. To correct it tack No. 0 sandpaper on a perfectly flat board and rub the brush on it gently until its surfaces are true. Kerosene is excellent to remove the sticky grease and dirt mixture that sometimes accumulates on the brush rigging. Carbon tetrachloride is still better.

Commutator Too Thin

(154) Commutators gradually wear down through friction. After being trued up repeatedly in a lathe the bars may become too thin to serve adequately. As the bars get thinner from wear the ends no longer have a

firm mechanical support, since the clamp or lock is near the center of the length of the bar. This condition will cause chattering, sparking and heating, because the individual bars are disturbed when the brushes pass over them. Install new bars.

Uneven Wear

(155) It is possible for some commutator bars to be slightly softer than others, and thus tend to wear down faster, causing sparking and a roughened surface. The remedy is resurfacing in a lathe.

Hot Brushes

(156) Too much heat in a brush indicates a misplaced brush or a poor contact. The brush is heated either from poor contact within itself, or because the other brushes in the same line have poor contact and carry practically nothing throwing the whole burden of carrying the current upon the hot brush. Examine the brush contacts and the brush pigtails. Remember that nearly all brush deficiencies produce heat.

Low Bearings

(157) This has been mentioned before, but is again referred to because worn bearings will, at least with some types of machines, throw the magnetic field sufficiently out of balance to cause sparking at the brushes. Here the air gap at the top of the armature will exceed that at its bottom. The gaps should be made equal. New bearings are indicated.

"Shorted" Coil

(158) A short-circuited armature coil puts the generator out of business promptly. The "shorted" coil will heat up quickly. The short may either be in the coil itself, or at a connection between two commutator bars.

Bent Armature Shaft

(159) A bent armature shaft is evidenced by increased vibration. It is unwise to attempt to have it

straightened. A new shaft is the only reliable remedy.

Overload

(160) Overload causes the whole armature to develop excessive temperature; it also causes brush sparking that cannot be stopped, though it can be reduced by shifting the brush yoke slightly from its normal position. (161) A well designed, well constructed motor-generator set should withstand an overload beyond its nameplate rating, which for projection work already presupposes a temporary overload. It should be able to withstand indefinitely a ten percent continuous overload beyond nameplate rating. Imposing a continuous overload in any amount, however, is very bad practice, as it makes for inefficient operation and rapid deterioration.

Weak Field

(162) If your generator does not pick up its load readily or will not retain its normal voltage while in operation, it is evidence that its field is weak. This fault in a motor will decrease its starting power but increase its speed and current consumption. (163) A weak field may have its seat either in a loose connection somewhere in the field circuit, or it may be caused by a short-circuiting of the current through field windings induced by weakened insulation caused by abnormal heat or otherwise; or it may be caused by a metallic short in the field coil. Test across each coil with a volt meter. The defective coil is the one showing the least drop. If all readings are identical, the trouble, you may be sure, is due to a loose joint in the magnetic circuit.

Undue Vibration

(164) Too much vibration in a generator may cause brush sparking. Immediately after installation of a new motor or generator, place your hand on its frame. If serious vibration is detected, refuse the machine. Modern motors and generators can be so balanced that there need be no discernible vibration.

Ring of Fire

(165) Should a ring of fire appear on the commutator it will be due to one of two things: it is either a current-carrying material that connects two or more commutator bars or it is an open circuit in the armature. If it is the first, the "ring" will be bright and pronounced. If it is impractical to stop the machine at the time, hold a piece of 00 sandpaper against the fire ring lightly. This should stop it unless the connection is in an undercut below the commutator surface. Don't use the sandpaper if it is practical to stop the machine and hunt up the defect.

(166) An open circuit in the armature will eat into the mica between the two bars connecting the faulty coil, and may invade the bars themselves. The machine should be stopped at once. It may be a broken coil wire or the commutator bars may have loosened and broken off one or more of the leads. The machine will be out of commission until the trouble is remedied, the length of time required for repairs depending upon how much damage has been done before the trouble is discovered.

Overheating

(167) Through continued overload, abuse or just plain carelessness, it may happen that temperature will develop in the armature and melt the solder connections between the commutator bars and coils. The liquid solder will be thrown out, though there may be no complete opening of the circuits. Stop the machine immediately or the commutator will be ruined.

Hot Bearings

(168) Should a bearing run hot, immediately drain and refill with fresh oil. See to it that the oil ring is not "stuck." If the heating is sudden and violent, shut the machine down and make a careful examination of the bearing. We are assuming, of course that the oil has not been permitted through carelessness to drop too low. If it has, drain the bearing, flush it out with thin oil to wash out a possible metallic scale induced by heat and refill with fresh oil.

(169) Never directly apply water to cool down a hot bearing unless you want additional trouble. (170) Sometimes when a moderate bearing heat develops, a change to a different oil, heavier or lighter, will correct the trouble. However the better plan is to keep the machine running, flooding it with a not-too-heavy oil, meanwhile putting cold applications on the outside of the oil well. Cloths wrung out of cold water should soon reduce the temperature so that the machine can be shut down without danger of the bearing and journal "freezing" together.

(171) When a bronze bearing in a new machine runs hot it is in danger of "freezing" to the shaft if the machine is immediately shut down and this means the bearing must be turned or chopped off the shaft and a new one installed.

Permissible Temperatures

(172) The fact that parts of a motor or generator feel uncomfortably hot to the touch does not necessarily indicate trouble. Every room in which motors and generators are located should be equipped with a reliable thermometer having, by preference, both Centigrade and Fahrenheit scales, the latter reading not less than 200 degrees.

(173) The standard regulations of the American Institute of Electrical Engineers permit a maximum temperature of 90 degrees Centigrade, which equals 194 degrees Fahrenheit, for motors and generators and any part thereof. Since the human body, ordinarily, has a temperature of about 98 degrees, a motor or generator part may feel very hot to the touch, though still at safe operating temperature. This feeling of danger is particularly true when on a hot day the perspiring hand is laid against any metal part of the set.

Measuring Motor Temperature

(174) Bed the thermometer ball in stiff putty, then bed the putty on the part to be measured, leaving it in contact for an ample time so the putty will heat fully

through. Be sure to use stiff putty, otherwise it will get very soft and run under the action of the heat.

To reduce Centigrade to Fahrenheit (C. to Fahr.), multiply degrees Centigrate by 1.8 and add 32. For example, 40 degrees Centigrate will be 40 x 1.8 plus 32 which equals 104 degrees Fahrenheit.

THE TRANSFORMER

1. Are transformers rugged devices?
2. May any transformer be used on any voltage?
3. May transformers be arranged to deliver different current volumes?
4. Of what does a choke or reactance coil consist?
5. What is reactance or "magnetic kick"? Define it.
6. How is a choke coil connected? How does it control current volume?
7. Are choke coils suitable for controlling projector light source current?
8. If a second coil of insulated wire is wound upon the core of a choke coil, what do we have?
9. To what is transformer secondary current due?
10. To what will the proportion of primary and secondary voltage be due?
11. Suppose both primary and secondary coils have an equal number of turns, what is the effect?
12. What is the primary purpose of transformers?
13. Where is secondary wattage derived and in what manner?
14. Of what does a transformer such as is used for controling projector light source current consist?
15. Do such transformers provide for stabilization of the arc?
16. How is different current volume (amperage) secured?
17. Why are primary and secondary coils placed close together?
18. Is every a.c. circuit wire surrounded by a magnetic field?
19. In what is magnetism measured?
20. What is a "Maxwell"?
21. How is a magnetic field "built up" or strengthened?
22. What should be the efficiency of a transformer?
23. At what maximum temperature will transformers operate safely?
24. Why should transformers never be located close to sheet metal?
25. May transformers be connected in parallel?

CHAPTER XI

THE TRANSFORMER

Transformers such as are employed in sound equipment will be treated elsewhere. Here we will consider only those used for controlling current for projection light sources where a.c. is used at the arc. Some explanation of the basic principles upon which they operate seems both advisable and necessary.

(1) Transformers of the kind we are now considering are very rugged and are designed for alternating current only. (2) A transformer can be used only on the voltage it is designed for. (3) Transformers may be built either to deliver one current volume only, or they may be designed to deliver different amperages merely by manipulating a switch or switches, or by making different connections.

The Choke or Reactance Coil

In Fig. 77 we see diagrammatic representation of what is known as a "choke" or reactance coil. (4) It consists of a bar of iron (usually built up from thin sheets of metal insulated from each other by means of an insulating, incombustible paint) upon which is wound turns of insulated wire few or many in number, according to the effect desired and the voltage it is to oppose.

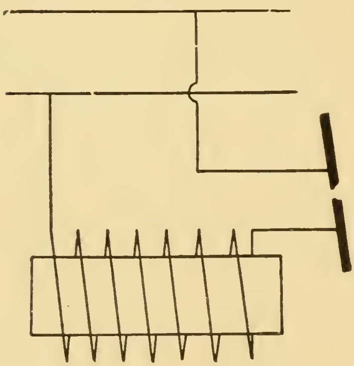

Figure 77

(5) This reactance offers what is commonly termed "magnetic kick," which is another term for magnetic reactance. The scientific definition of reactance is as fol-

lows: "In an alternating current circuit, a resistance having self-induction equal to the component of the impressed electromotive force at right angles to the current, divided by the current. It is expressed in ohms."

(6) The coil winding is connected to one side of an a.c. circuit, upon which its reactance will have the effect of creating a counter E.M.F. that will oppose the supply voltage, and thus current flow will be controlled.

(7) Choke coils may be and in earlier days were to some extent employed to supply current to projector light sources, but they are not at all suited to this kind of work.

The Transformer

(8) If, however, we wind upon the same bar of iron (called a "core") a second coil of insulated wire, we would have a crude transformer. If we send a.c. through the first coil we shall find that although the two coils of wire are insulated from each other and from the iron core, with no metallic connection whatsoever between them, there will be nevertheless an E.M.F. created in the second coil, which, when the second coil is connected to a closed circuit will cause current to flow. This current is known as "secondary current."

(9) This secondary current is due entirely to magnetic induction. Each time the current in the first, or "primary" coil changes direction the magnetic field generated by its action will "induce" or generate an E.M.F. in the secondary coil (10), which will have voltage with relation to the primary (line) voltage in exact proportion to the number of turns of wire in the primary and secondary coils. For example (11), if the primary coil is supplied with 220 volts pressure and both coils have an equal number of turns, then, save for the small losses natural in such an equipment, the secondary voltage would be 220. If we supply the primary coil with 220 volts and the secondary coil has only one-fifth as many turns as the first, then the secondary voltage (disregarding losses) will be one-fifth that of the primary, or $220 \div 5 = 44$. We would thus have what is known as

a "step-down" transformer. When a "step-down" transformer delivers ten amperes of secondary current at 44 volts or (44 × 10) 440 watts, it takes (440 ÷ 220) 2 amperes from the primary coil again disregarding losses. If each of the two coils had the number of turns of the other, the transformer would be a "step-up," and we would have a secondary voltage five times that of the primary.

(12) This is the purpose and function of the transformer—the raising or lowering of voltage. (13) Let it be understood that all wattage (voltage × amperage) taken from the secondary coil is subtracted from the primary one. Through magnetic induction the primary supplies the secondary with power, and that power, plus losses inherent in the transformer, is taken from the primary just as though the power were supplied by an actual electrical connection through metal. Step-down transformers increase amperage exactly in the proportion that voltage is decreased.

(14) Low voltage transformers, such as are used to supply a.c. light sources, consist of a laminated iron core and a primary and a secondary coil. The coil turns are proportional to the supply of voltage required to force the required amperage through the arc resistance.

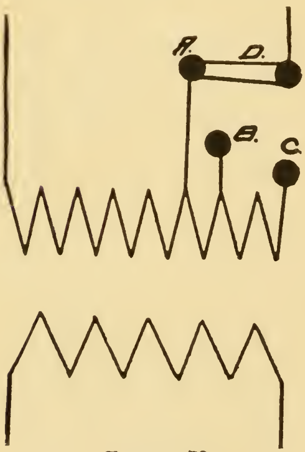

Figure 78

(15) In all low voltage transformers there is an arrangement that stabilizes the arc in much the same manner as ballast resistance does. (16) Such transformers are usually supplied with various leads connecting with switch contacts as shown in Fig. 78. Each of these leads connects to the primary coil at different points, so that by manipulating the switch or switches, some of the primary turns may be cut out or, conversely, may be put into operation, thus altering the

relation of the primary and secondary turns and therefore the secondary voltage.

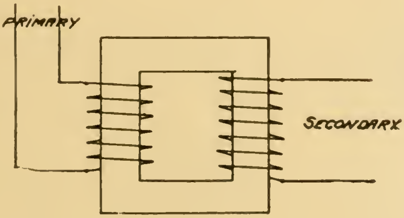

FIGURE 79

In Fig. 79 we see a diagrammatic representation of a transformer in crude form. (17) In actual practice the coils are wound very differently, usually one inside the other and very close together in order to locate the secondary in the strongest part of the magnetic field induced by the primary coil, which will be close to the primary coil itself. Remember, power is not taken directly from the primary in the form of E.M.F., but by magnetic action in the form of a separately induced E.M.F., the formation of which requires that power exactly equal to it, measured in watts, be taken from the primary current. We dwell upon this because this is the germinal point that must be clearly understood before transformer action can be grasped.

And now let us go back and examine matters from another angle. (18) Every a.c. circuit wire is surrounded by a self-induced magnetic field created and maintained by the action of the E.M.F. with which it is charged.

(19) Magnetism is measured in "Maxwells." (20) A Maxwell is the unit of magnetic flux or action. It represents the number of lines of magnetic force passing through each square centimeter of a field of unit density, which latter is "the unit value of flux density—or intensity is one line or maxwell per square centimeter of the magnetic field area."

In Fig. 80 we see a circuit wire (A) surrounded by lines of magnetic force. Note that they weaken grad-

FIGURE 80

ually as distance from wire A increases In the magnetic field thus created we see wire B, in which, under conditions shown, would be created an E.M.F. too weak to be detected by anything but a very sensitive galvanometer. Such an arrangement would therefore have no commercial value. It is only shown to illustrate the fact that the magnetic field exists, which is the base upon which all transformer action rests. The action would occur only at each starting or stopping of the current.

Building Up the Field

(21) If we wind a portion of wire A, Fig. 80, into a coil about B, since the magnetic action shown in Fig. 80 exists along its entire length, it is readily seen that the field, viewed as a whole, will be built up so that much magnetic action will be crowded into relatively very little space, and therefore its action per unit area is intensified. The action still would be too weak to have commercial value in production of power. If we now thrust into the central opening of this coil a bar of soft iron such as has been described in place of wire B, we shall find the magnetic action instantly increased, or intensified, because the bar of iron has become a magnet, and has set up a powerful magnetic field.

Efficiency

(22) A well designed, well constructed transformer should have an efficiency well above 90 percent. Efficiency may be calculated in percentage by measuring the input and output wattage, and dividing the output by the input.

Transformer Temperatures

(23) Any transformer part will operate with safety

so long as its temperature does not exceed 90 degrees Centigrade, which is equivalent to 194 degrees Fahr.

LOCATION

(24) Never locate a transformer close to sheet metal since its magnetic action may set up vibration in the metal, causing objectionable noise and loss of power.

TRANSFORMER CONNECTIONS

(25) Provided both meet voltage requirements two or more transformers may be connected in parallel (multiple). Two or more different "makes" of transformers may be so connected. The resultant current will be the sum of both their outputs. Connect one of the

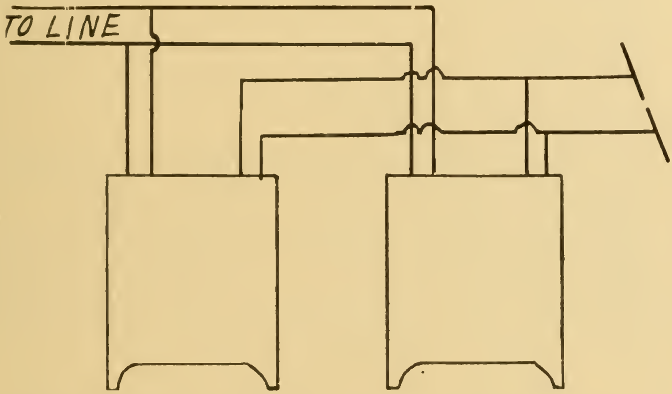

FIG. 81.—Multiple connection. Switches and fuses omitted.

supply wires to one side of all primaries and the other to the other side of all primaries. Then connect one side of all secondaries to the power-using device, an arc lamp for example, and the other side of all secondaries to the other side of the device. The connection is shown in Fig. 81.

CARBONS

1. How may millimeters be reduced to inches?
2. What qualities must projection carbons possess?
3. Do carbon cores contain chemicals?
4. Must carbons be free from moisture when used?
5. For what reasons was carbon selected as the base of electric arc electrodes?
6. At what temperature is carbon volatilized—transformed into gas? 3500
7. What is the luminosity of carbon at the point of volatilization?
8. Does the conductivity of carbon increase as temperature is increased?
9. Is carbon core conductivity higher than that of the surrounding shell?
10. Are carbons made in all lengths required for arc lamps?
11. Describe the general process of making a carbon.
12. What is the "crater" and how is it formed?
13. What effect will impurities in a carbon have on illumination.

Effect of Moisture, page 339

14. What are the harmful effects of moisture?
15. Where should carbons be stored?
16. How many spare carbons should be carried in stock.
17. What precautions should be taken when the theatre changes its brand of carbons?

Carbon Diameters, page 340

18. Is it essential that the carbons match the amperage?
19. What will be the effect of an oversized positive carbon?
20. What are the advantages of a small negative carbon tip?
21. What is meant by a carbon "spindling"? May it occur to both carbons simultaneously?

22. What causes spindling?
23. If your carbons are not overloaded but spindle, what is the first thing that demands your attention?
24. Name the effect of positive carbon spindling. Of negative carbon sprindling.
25. Does spindling tend to injure the metal parts of high intensity lamps?

Inspection of Carbons, page 342

26. What requires special attention in newly purchased carbons?
27. What is important in regard to carbon cores?
28. Are small cracks running lengthwise in low intensity carbons harmful?
29. What about circumferential cracks?

Using Carbon Stubs, page 342

30. Is the use of carbon stubs questionable economy?

Mushroom Carbon Tips, page 343

31. What is a mushroom tip and what causes it?

Carbon Deterioration, page 343

32. Do properly stored carbons suffer any harm because of age?
33. What are the proper SRA combinations and what is the amperage range of each.
34. In what various diameters are SRA positives made? What is the capacity of each?
35. What if these carbons are overloaded?
36. If these carbons are forced above capacity is screen illumination increased?
37. How is candle power resulting from various amperages calculated?
38. What candle power can SRA carbons produce?
39. What size carbons must be used for different types of equipment of all amperages.

10MM, 5800 to 6850 C.P.
12MM, 6750 to 9950 C.P.

CHAPTER XII

CARBONS

(1) Carbon diameters are very often stated in millimeters (mm.) One mm is 0.03937 of an inch, hence millimeters may be reduced to inches by multiplying the mm diameter by 0.03937 thus; a 12 mm carbon would be $12 \times 0.03937 = .47244$, or about one-half of an inch in diameter.

Carbons used in modern motion picture projection work must have certain well-defined qualities. (2) They must, within very narrow limits, be straight, uniform in texture and, except for the core, of uniform density throughout. They must, to all intents and purposes, be entirely free from impurities. They must, within very narrow limits, be made in exact diameters, each diameter suited to a given range of current flow. (3) Their cores must contain certain materials, some of them chemical in nature, the exact composition of which is determined by the uses to which the carbon is to be put. (4) Carbons must be free from all moisture at the time they are used or results will not be the best.

(5) Carbon was selected as the base for arc lamp electrodes because it is the one available material able to withstand the action of heat up to (6) approximately 3,500 degrees Centigrade, at which point it is finally "volatilized," that is, transformed into gases except for a very small residue of ash. (7) At such temperature it is very brilliant. In fact the luminosity produced is second only to that of the sun itself. Carbon may be reduced to a very fine powder, mixed with available, relatively cheap binders and moulded into rods of exact diameter having sufficient strength and rigidity to serve all the needs of practical projection work.

(8) In the form of finished rods, carbon has excellent conductivity which, contrary to the action of most other

conductors, increases as its temperature is increased.

(9) In the process of manufacture a central opening of required shape and diameter is provided, later filled in with a core mixture of such nature that the core conductivity is much higher than that of the carbon shell. The purpose of the core is to steady the arc and hold it in a fixed central position; also in the core certain materials, chemical in nature, are intermixed, and these serve to whiten or otherwise alter the color or tone of the light, and serve other useful ends.

(10) Carbon rods are made in all lengths and diameters which projection practice demands. They are relatively inexpensive.

(11) The carbon, except for its central core, is composed entirely of carbon powder very similar to the product known to us as "lampblack." This powder having first been subjected to the action of powerful magnets to remove metallic impurities, and put through other purifying processes, is thoroughly mixed with a binder of pure pitch. The resultant "dough" is then forced, under very heavy pressure, through a round role in the center of a steel plate or "die," the diameter of which corresponds to the diameter of the carbon it is desired to make. If a cored carbon is to be made, a steel needle is fixed in the center of the opening in the die, so that a hole is left in the carbon rod. The carbon comes from the die in the form of a continuous rod, which is afterward cut into proper lengths and subjected to a baking process in ovens or kilns. Baking reduces the pitch binder to carbon. After cooling the rods are removed and the core, if it is to be a cored carbon, is forced in under very high pressure.

The rods are then baked again to reduce the core to the necessary condition; they are cleaned, tested for straight-

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There are many who will remember what a very crude product the carbon was, when along about 1912, partly at the insistence of the projection department of the old Moving Picture World, the National Carbon Company undertook to improve carbon quality and the work has been carried steadily forward until today the projection carbon is a remarkably perfect product.

ness and possible defects, cut to proper lengths, pointed, and, after inspection, packed for shipment.

We have outlined very roughly the process of manufacture. There is very much more to it, such as the inspection and testing of materials at various stages, etc. It is impractical to set forth the many elements that enter into carbon cores. They are, for the most part, either patented or well guarded trade secrets, promulgation of which would serve no useful purpose so far as concerns the projectionist.

The carbon rod surrounding the core (where there is a core) provides most of the crater floor area. The core serves several purposes as already indicated but in addition the various chemical elements with which it is impregnated make it either a high or low intensity carbon, or any one of several other sorts, including White Flame and a.c. carbons.

(12) What is known as the "crater" of the electric arc is the light source. It is formed by the heating of the positive carbon tip through current action, to the point where the carbon particles are volatilized (at about 3,500 degrees Centigrade or 6,300 Fahrenheit) into gases. In this manner a shallow, saucer shaped depression is formed and its floor or bottom called the "crater floor," is the light source, except in the case of high intensity, where gases contained in the crater form the light source.

(13) It is essential to good results that the entire area of the crater floor have, as nearly as possible, an even temperature, which gives a uniform luminosity. This can be accomplished only by the use of very pure carbon materials. Should impurity occur at any point, or carbon density vary at different points of the crater floor, there will be a variation in the resistance to the current; as a result current flow and luminosity will not remain constant until the fault, whatever it be, has burned away. This being self evident, we may readily understand the importance of pure materials and of good mixture to provide uniform density of the carbons at every point.

In the high intensity carbons the source of light is very largely the highly luminous gas or vapor contained in the positive carbon crater and held therein by the negative gas stream. This in no degree lessens the necessity for evenness of resistance at all points of the crater floor, excepting only the difference inherent between the core and surrounding carbon.

Effect of Moisture

(14) Best results cannot be had from carbons impregnated with moisture. Under the action of heat moisture will be converted into steam, which, because it cannot be instantly expelled, will set up high pressures at points within the body of the carbon and create a very harmful situation. Minute particles will blow off from the crater floor causing the light to flicker.

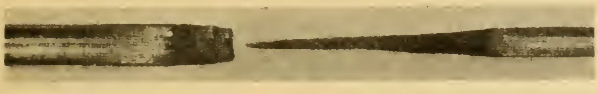

Fig. 82.—Effects of overloading a negative carbon. It gives a poor light because it is badly "spindled."

This is what is often called "sputtering of the arc." It is most in evidence when the moisture is contained in the positive carbon, though the effect may, in lesser degree, be produced from moisture in the negative.

(15) Carbons should be kept in a warm, dry place for several days before they are used. (16) Two or three bundles of carbons, of all types and sizes should be kept constantly in stock, stored in the warmest, driest place available. It is a good plan to lay in a three months' supply, replenishing the stock every thirty days thereafter, always using those longest in stock.

(17) We suggest that before purchasing any carbons newly marketed, the projectionist obtain a small number of the right diameters for a trial in his own theatre. If they seem to work well, it is safe to purchase a full bundle of positives and negatives to try them out thoroughly.

High Intensity Carbons

High intensity carbons differ but little if at all from other kinds as regards the material composition of their body or shell. The materials in the core of a carbon differ widely from those composing its shell, the exact composition being largely a trade secret. It contains chemical compounds of the cerium group of metals known to chemists as the "Rare Earth Group." Very naturally carbon manufacturers do not disclose their formulas, but such knowledge is of no practical value to projectionists. The high intensity arc is treated fully under "Light Source."

Effect of Carbon Diameters

(18) To secure best results in projection the capacity of the carbons must be very carefully matched with the amperage. (19) If the positive carbon is too large in diameter the arc will be inclined to unsteadiness. If the negative is too large there will be undue interference by the unnecessarily large tip, which means waste of light.

While it is quite true that with a carbon trim of excessive current capacity it will not be necessary to trim the lamp so often, and may even save a bit in carbon cost, such saving nevertheless represents very poor practice. It results in an unsteady light of relatively poor quality, and at such a price any small saving in carbon cost is an absurdity. Any projectionist worthy of his hire will select and use only carbons of a kind and diameter in combinations recommended by the carbon manufacturer for the amperage and type of light source he is using.

(20) Keeping within range of proper current capacity, the smaller the negative carbon the smaller will be its tip and consequently the less light it will obstruct and waste; but if the negative tip be unnecessarily large it encourages a tendency in the arc to be unsteady and to "travel," producing light fluctuations which are revealed on the screen.

Use the smallest negative carbon possible without inducing spindling but remember that the carbon makers have set up limitations which should be strictly adhered to. Copper coating aids materially in diameter reduction.

Carbon Spindling

(21) "Spindling" means the burning of a carbon tip to an abnormally long, slim point as illustrated in Fig. 82. It may occur to either or both positive and negative. It is an exceedingly bad condition making for poor light and waste of power. (22) It may be due to overloading—using amperage above the rated capacity of the carbons. It may be caused by lack of proper, firm contact between the carbon and carbon jaw over the entire area of the contact surface, which in turn may be due to (a) loose contact, (b) roughened or pitted carbon jaw; (c) dirty contact surface, or (d) in some cases by current entering the carbon too far from the carbon tip. This last seldom happens except in those intensity lamps where the carbons are working above their rated capacity. Whatever its course it will be aided materially by high temperatures in poorly ventilated lamphouses.

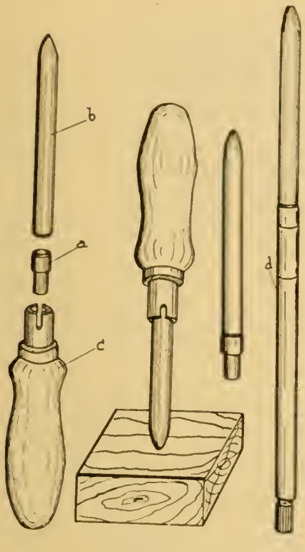

Figure 83

(23) If your carbons seem inclined to spindle and yet are not being forced above their rated capacity, first make sure that the lamphouse has proper and continuous ventilation. Examine the carbon jaws, making sure they are clean, not pitted, and that when tightened up they clamp the carbon firmly through their entire area.

(24) The net effect of penciling of the positive carbon is a reduction of the light source area and a reduction of the current flow due to the increased resistance offered by the small penciled part of the carbon. The penciling of the negative carbon by increasing the resistance, decreases the amperage flow, and so decreases screen illumination. Penciling may or may not cause an unsteady arc.

(25) In high intensity arcs the metallic parts of the lamps are close to the very hot light source, and here penciling makes damage.

Inspection of Carbons

(26) Newly purchased carbons should be examined carefully. Inspect the core ends, which should, in each carbon, fill the opening completely. There should be no defects, though an occasional small fault need not cause rejection of a bundle of carbons.

(27) It is manifestly essential to steady light production that carbon cores be continuous, and that they fill their space completely, adhering to its walls tightly. Otherwise short sections may drop out as the carbon is consumed, with disastrous effect upon the screen illumination.

(28) No attention need be paid to small cracks running lengthwise in low intensity carbons. They do no particular harm and are, in a manner, characteristic of the product. It is extremely unlikely that any crack will be found so wide or deep as to cause trouble.

(29) Narrow and shallow cracks around low intensity carbons should be tolerated but circumferential cracks of more than superficial depth may cause a carbon to break while in use. Cracks of any sort in high intensity carbons are a cause for rejection. They are very deterimental to screen illumination. It may be assumed safely, however that all carbon manufacturers compel a severe inspection of their product before it leaves the factory.

Using Carbon Stubs

(30) Although projectionists should burn their carbons as short as possible, it is questionable economy to attempt to make use of carbon stubs by joining them, more or less imperfectly to whole carbons or other carbon stubs. Several devices* have been perfected for the

*The carbon saver marketed by the Projection Improvement Company is very simple and with ordinary care should last indefinitely. It consists of a metal tipped handle, c, as shown in Fig. 83, a heavy, hollow, copper-coated steel rod, d, a block of soft wood and certain copper caps, a. They purpose of such jointure, but in view of the urge to reach perfect screen illumination the practice of using stub ends is backward motion.

FIGURE 84

Mushroom Points

(31) What is known as a "mushroom" carbon tip is illustrated in Fig. 84, in which a mushroom appears on the positive (at the top) and a negative (at the bottom). It is caused by burning an arc too short. The only remedy is to carry a longer arc.

Carbons Do Not Deteriorate

(32) Carbons, properly stored, will be just as good ten years after storage as when made, provided they have absorbed no moisture.. If they have, after a thorough drying out, they will be as good as ever. Store them, if possible near the ceiling of the projection room, where they will dry out thoroughly.

Recommended SRA Combinations

SRA projection carbons are designed for low intensity

may be had for high intensity or for Suprex carbons. The process of using them is as follows: A cap is slipped on the rear (unburned) end of the stub. The other end of the cap then is shoved into the recess in upper end of handle c. The end of the stub is then rested on the wooden block, which must be of soft wood to prevent breaking the crater edges, and the upper end of the handle is struck a sharp blow with the palm of the hand. This not only shoves the cap tightly on the carbon end, but clamps it there immovable and in good electrical contact. The handle then is pulled off and the cap inserted in a recess in the end of rod d, and a knurled nut at its bottom is turned clockwise, which clamps the cap tightly into the rod.

reflector type lamps which use a maximum current of 28 to 42 amperes. (33) The current range and combinations are as follows:

28 to 32 amperes, 12 mm positive, 8 mm negative.
32 to 42 amperes, 13 mm positive, 8 mm negative.

(34) At the present time this covers the range of amperage in general use. There are positives made in 10, 12, 13 and 14 mm diameters having a current range of 21 to 24; 28 to 32; 32 to 42 and 42 to 52 respectively. (35) These four sizes may be expected to produce an unsteady arc if current up to or in excess of 25, 34, 44 and 55 amperes respectively is forced through them.

(36) Forcing these carbons above their maximum capacity adds but very little to the illumination of the screen. On the other hand, burning them below maximum capacity will produce the same effect—an unsteady arc and unsatisfactory screen illumination.

(37) Approximate candle power may be calculated for different amperages. Taking the 12 mm combination as described above, at 28, 31 and 34 amperes the crater floor will have the following square mm areas: 49, 53.5 and 60. The 13 mm carbon crater floor will, at 34, 40 and 44 amperes, have square mm areas of 61, 72.4 and 77.9.

The crater brilliancy per square mm of these carbons is given as 130 to 175 candle power. A fair average for d. c. arcs is 165 c. p., so if we multiply the square mm area of the crater floor by 165, we shall have a very close approximation of the total candle power, though not all of it will be available to the collector element (mirror) under even the best conditions. The above c. p. is for d. c. arcs only. The average a. c. is 130 c. p. per square mm.

(38) Within their current range SRA carbons are capable of giving from about 5,800 to 6,880 candle power for the 10 mm trim; about 6,750 to 9,950 candle power for the 12 mm trim; about 10,200 to 12,000 for the 13 mm trim and about 14,250 to a trifle more than 15,000 candle power for the 14 mm trim.

(39) Proper Carbon Combinations*

D.C. STEREOPTICON, REFLECTOR TYPE

15 to 20 amperes, 10 mm positive, 7 mm solid or cored.
21 to 25 amperes, 12 mm cored positive, 8 mm cored negative.
26 to 30 amperes, 13 mm cored positive, 9 mm cored negative.
28 to 32 amperes, 12 mm SRA cored positive, 8 mm SRA cored negative.
32 to 42 amperes, 13 mm SRA cored positive, 8 mm SRA cored negative.

D.C. LOW INTENSITY SPOT AND FLOOD LAMP

30 to 40 amperes, ⅝" positive, either ½" or 9/16" negative.
40 to 50 amperes, ⅝" positive, 5/16" negative.
50 to 55 amperes, ¾" positive, ⅝" negative.
55 to 65 amperes, ¾" positive, 11/32" negative.
65 to 70 amperes, ⅞" positive, 11/32" negative.
70 to 85 amperes, ⅞" positive, ⅜" negative.
85 to 100 amperes, 1" positive, ⅜" or 7/16" negative.

D.C. HIGH INTENSITY SPOT AND FLOOD LAMP

All carbons are White Flame positives and Orotip negatives or their equivalents. All carbons are cored.

89 to 95 amperes, 11 mm positive, 11/32" negative.
100 to 110 amperes, 13.6 mm positive, ⅜" negative.
110 to 125 amperes, 13.6 mm positive, 7/16" negative.

A.C. LOW INTENSITY SPOT AND FLOOD

All carbons both negative and positive are A.C., White Flame or their equivalent and all are cored.

30 to 60 amperes, ⅝" positive, ⅝" negative.
60 to 80 amperes, ¾" positive, ¾" negative.

D.C. REFLECTOR TYPE ARC WITH SOLID NEGATIVE

This is for horizontal trim lamps, cored positive, solid negative.

10 to 15 amperes, 9 mm positive, 6.4 mm negative.
16 to 20 amperes, 10 mm positive, 7 mm negative.
21 to 25 amperes, 12 mm positive, 8 mm solid or cored negative.
26 to 30 amperes, 13 mm positive, 9 mm cored negative.
31 to 35 amperes, 14 mm positive, 10 mm cored negative.

SAME AS ABOVE, BUT FOR LAMPS IN WHICH THE NEGATIVE CARBON IS AT AN ANGLE TO POSITIVE

6 to 10 amperes, 9 mm positive, 8 mm negative.
11 to 15 amperes, 10 mm positive, 9 mm negative.
16 to 20 amperes, 11 mm positive, 10 mm negative.

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*The following carbon sizes and combinations are those officially approved for National carbons. For carbons of other manufacture this information can be secured directly from the distributor.

FOR OLD TYPE D.C. ARCS

25 to 50 amperes, ⅝″ cored positive, 5/16″ orotip negative.
50 to 65 amperes, ¾″ cored positive, 11/32″ orotip negative.
65 to 70 amperes, ⅞″ cored positive, 11/32″ orotip negative.
70 to 85 amperes, ⅞″ cored positive, ⅜″ orotip negative.
85 to 120 amperes, 1″ cored positive, 7.16″ orotip negative.
120 to 140 amperes, 1⅛″ cored positive, ½″ orotip negative.

FOR OLD STYLE A.C. ARC

The following White Flame carbons are recommended, in all cases both positive and negative being of the same diameter:

25 to 40 amperes, arc voltage 25 to 28, ½″ carbons.
40 to 60 amperes, arc voltage 28 to 32, ⅝″ carbons.
60 to 75 amperes, arc voltage 32 to 35, ¾″ carbons.
75 to 100 amperes, arc voltage 35 to 40, ⅞″ carbons.

THE LIGHT SOURCE

1. What two light sources are employed in projection?
2. Is there a wide variation in available arc light sources?
3. Is special treatment of each arc light source essential to best results?
4. How is an electric arc formed?
5. What becomes of the carbon particles?
6. How is a conductor of high resistance established between the incandescent carbon tips?
7. What is the "crater" of an electric arc? How is it formed?
8. What is the temperature of the crater floor?
9. How does an electric arc crater floor compare in brilliancy with other light sources?
10. What substance will withstand the highest temperature before being transformed into a gas?
11. Why will no current flow until the carbon tips are in actual physical contact?
12. Why will current flow after the carbons are again separated?

Illumination Values, page 358

13. How does the illumination of an electric arc crater compare with its brilliancy and area?
14. What is the approximate brilliancy of the old style straight arc per square mm of crater floor area? Of the low intensity arc? Of the reflector type high intensity arc? Of the straight high intensity arc? Of the old style a.c. arc? Of the new style high intensity a.c. arc? Of the new non-rotating high intensity d.c. arc?
15. How would you calculate the total light producing power of an electric arc?
16. How is the total candle power of a crater floor calculated?
17. Why is a core necessary in the positive carbon of a d.c. arc? In both carbons of an a.c. arc?
18. What is the depth of the incandescent film on a crater floor?
19. Why is the very thin depth of the incandescent film on the crater floor an argument against under-loading carbons?

20. Is the light from the arc tail flame of any value in illuminating the screen?
21. Why is the tail-flame more likely to decrease than increase screen illumination?
22. How must the crater floor face the collector lens or mirror for maximum results?
23. How may horizontal trim carbon craters be made to face the collector squarely?
24. Must positive and negative carbons be in perfect alignment sidewise?
25. If the crater of the horizontal positive carbon tends to slope backward on either upper or lower side, what should be done?
26. Why is it important that the crater face the collector lens or mirror squarely?
27. What about the distance of the crater from the collector lens or mirror?
28. What is the effect of locating the light source too close to or too far from the collector?
29. What determines the proper distance of the light source from the mirror collector?
30. What arc voltage should be maintained?

STRAIGHT HIGH INTENSITY LIGHT SOURCE, PAGE 361

31. What is a straight high intensity light source?
32. What is the brilliancy of straight high intensity craters per square mm?
33. Why should the straight high intensity light source be operated carefully?
34. Is high intensity very sensitive to improper adjustment?
35. What is the total candle power of high intensity at different amperages?
36. What is the correct adjustment of the high intensity arc?
37. Is arc voltage a safe guide in operating the high intensity light source?
38. From what does the major portion of high intensity light emanate?
39. Is high intensity light more brilliant than carbon at the temperature of volatilization?
40. Must the high intensity crater be kept filled with gas?
41. By what is the gas confined to the positive crater?
42. In exactly what position should the negative carbon tip be?

43. What are the correct measurements between positive and negative carbon tips with a 16 mm trim.
44. Do the various makes of high intensity lamps all perform the same functions?

High Intensity Positive Contacts, page 363

45. Of what are high intensity lamp carbon contacts made and how long should they last?
46. What should be done with badly burned or pitted carbons?
47. Is it practical to use a file on contact points?
48. Describe the best method of cleaning positive contacts.
49. What can be used in place of a bar in the cleaning process?
50. How can a minor swelling on the face of the contact be smoothed off?
51. What forms on the face of high intensity contacts and what will happen if it be not cleaned off frequently?
52. How often should high intensity contacts be cleaned?
53. Should spare contacts be carried in stock?

Positive Carbon Rotation and Feed Unit, page 366

54. Is the positive carbon rotated and fed forward by the same element?
55. Must moving high intensity lamp parts be lubricated? With what?

When Positive Carbon Fails to Feed Forward, page 367

56. When the positive carbon fails to feed forward what is the trouble?
57. How much tension should the feeding mechanism apply to the carbon?
58. What may result from too much or too little tension?
59. What should be done if the positive carbon ceases to rotate or feed forward?
60. How do you make a quick test for roughness of contact or for excessive contact tension?

High Intensity Carbon Contact Pressure, page 368

61. What does improper contact pressure cause?

62. Must the contact pressure have careful constant attention?
63. Should spare feeding mechanism parts always be kept in stock?

THE FLAME SHIELD, PAGE 368

64. What is a flame shield and what is its purpose?
65. What attention does the hole in the flame shield require?
66. What should be done each day before the performance begins.
67. Should a high intensity lamp be operated without a flame shield?

THE NEGATIVE HEAD, PAGE 369

68. What is the negative head?
69. How must the negative head be adjusted?
70. Describe the negative head current carrying contact.
71. How should the negative carbon bear upon the groove or grooves?
72. Must care be taken to position the negative carbon properly?
73. What is important in regard to the negative head?
74. What other items must be watched in the high intensity arcs?
75. What is the effect of burning the high intensity below or above its rated capacity?

SPEED OF CARBON CONSUMPTION, PAGE 370

76. What is the burning rate of the 9 and the 13.6 mm high intensity trim?
77. Why should you know the exact consumption speed of the carbons you employ, regardless of what type lamp you are using?
78. How can you calculate carbon consumption speed?
79. Is an ammeter a necessity?
80. What are the harmful results of inadequate lamphouse ventilation?
81. How much lamphouse ventilation should be maintained?
82. Why should the dowser be closed when striking the arc?

83. What should be done after running each reel?

Reflector Type High Intensity Lamps, page 371

84. Is the straight high intensity arc and reflector type high intensity the same?
85. What is the amperage range for the reflector high intensity arcs?

Low Intensity Light Source, page 371

86. Does the reflector type low intensity arc supply high light values
87. Why is this true?
88. Does the total light production power vary and for what reasons?
89. What is the candle power of the low intensity arc per square mm of crater floor area?
90. How much may the current flow vary in amperage?
91. What is the average increase in the crater area for each added ampere of current?
92. Is brilliancy of the carbon core uniform?
93. What elements demand constant attention when low intensity, reflector type light sources are employed?
94. How is the condition of wires inside the lamphouse determined?
95. What attention does the mirror require?
96. How are mirrors cleaned?
97. Describe how to fix the right distance of the arc from the mirror.
98. What lubricant should be used in the lamp?

Old Style D.C. Arc, page 375

99. Give a short summary of the necessary operating conditions for the old style d. c. arc.

New High Intensity A.C. Carbon Arc, page 375

100. What was the efficiency gap between the high and low intensity light sources before present day developments?

101. In what two ways did this difference manifest itself?
102. How does low and high intensity light compare?
103. What proportion of American and Canadian theatres are using low intensity light sources?
104. What is the practical effect claimed for the new a.c. and d.c. high intensity low amperage arcs?
105. What two types of carbon have been devised for the new a.c. high intensity arc and the new non-rotating positive d.c. arc?
106. What is the new a.c. high intensity arc?
107. How is the energy concentrated to yield a brilliant light?
108. How does the quantity of light projected to the screen compare with that of low intensity employing same optical train?
109. Does the color of the light closely approximate that of the d.c. high intensity light?
110. Is the cost of equipment less than that of the low intensity d.c.? Why?
111. Does it require any ballast resistance?
112. What diameter carbons are used for the a.c. high intensity light source? Are they copper coated?
113. In what position do the carbons lie?
114. What type of mirror reflector is employed?
115. What feed control is employed?
116. Should the lamp manufacturer's operating instructions be followed implicitly?
117. What is the voltage rating of the carbons employed with this arc? What is their burning rate and current density?
118. What is meant by current density? How is it calculated?
119. How does the a.c. high intensity carbon current density compare with that of the low intensity and the d.c. high intensity?
120. Where are the carbons gripped in the different types of arcs?
121. Why are the carbons copper coated?
122. What becomes of the copper?
123. What happens if the carbon is overloaded?
124. If the carbon is not overloaded will the copper burn away properly?
125. Must the arc be burned exactly right in order to obtain best results?
126. How far should the copper coatings be from the ends of both carbons?
127. Of what does the arc itself consist?

128. What effect does the change in current values have upon the arc?
129. What happens in the course of decreasing the arc length to 0.23 of an inch?
130. What happens when the arc is at 0.23 of an inch or less in length?
131. How long may the arc be without impairing its efficiency?
132. What effect have external disturbances on the arc?
133. Between what arc length limits (inches and volts) may the arc be expected to perform properly?
134. What is the amperage rating of the 7 mm trim?
135. What is the corresponding arc gap limits for proper operation?
136. What must be the feeding capacity of the carbon control?
137. What are the allowable variations in the arc control feed?
138. What will be the effect upon the arc control if the arc length varies widely?
139. Is it possible to adjust an arc control to maintain exactly one arc length?
140. Can an a.c. high intensity arc take current through rheostats?
141. Should transformers be adjustable to meet changing amperage?
142. Is "flickering" visible to the eye?
143. What is an oscillogram?
144. Read the text and then analyze some of the oscillograms shown in Fig. 99.

Low Amperage Non-rotating H.I. Arcs, page 392

145. What is the effect of high and low electrode current density upon light source brilliancy per unit area?
146. How does the non-rotating high intensity carbon differ from other light sources?
147. What elements in light sources are important in considering screen illumination values?
148. What are the chief characteristics of the high intensity arc?
149. Before the non-rotating carbon what was the smallest carbon diameter available? How many amperes did it require for satisfactory operation?
150. What is the big difference between the non-rotating carbon and the larger diameter high intensity light source?

151. What other factors of the non-rotating carbon make it extremely efficient?
152. What is the importance of the gas stream in all high intensity arcs?
153. How does the position of the negative and positive carbons affect the gas stream?
154. Must the carbons be precisely in line with each other sidewise?
155. Do extreme air drafts disturb this type of arc?
156. How can the arc be protected by air currents set up by the rear shutter?
157. Can these carbons be underloaded or overloaded without affecting their efficiency?
158. What is the relative efficiency between the 8 mm and the 7 mm trim?
159. How many light tones are there in high intensity light sources?
160. What conditions the tone of light that reaches the screen?
161. Is correct adjustment of the arc control very important.
162. Once having obtained the best crater position how can it be maintained?
163. Do the positive and negative carbon burn at an equal rate in all high intensity light sources?
164. What does the non-rotating carbon arc require of rectifying devices?
165. Is the use of a single-phase rectifying device permissible?
166. Is a two or three phase rectifier acceptable?

MAZDA LAMP, PAGE 398

167. What advantage does the Mazda lamp light source possess?
168. How does the Mazda compare with other light sources for motion picture projection?
169. What is the character of Mazda lamp screen illumination?
170. Is Mazda suitable for the projection of color pictures?
171. Should projectionists handling Mazda know its peculiarities?
172. In what way does the Mazda lamp produce light?
173. Of what is the Mazda filament made? What property enables it to produce the highest illumination of all other light sources save the electric arc?
174. With what are Mazda bulbs filled? What is its effect?

175. What is the useful life of the Mazda projection lamp?
176. What are the characteristics of the monoplane type of Mazda projection lamp?
177. What are the advantages of the biplane type of Mazda?
178. What governs the voltage that may be applied to a Mazda?
179. Why is the low voltage lamp used rather than the 115-volt lamp?
180. Why is a tubular small diameter bulb used?
181. What advantage is there in the tall bulb?
182. Can Mazda be made to operate successfully at either constant current or constant voltage?
183. What happens when the filament burns away?
184. How may deposits in the interior of Mazda bulbs be removed?
185. Is constant voltage and current flow necessary to good operation?
186. What governs Mazda's powers of screen illumination?
187. Is Mazda power affected by inexact adjustment of parts?
188. What should be done if the filament sags?
189. Should the full operating load of current be switched directly on a cold filament?
190. What provision is made for warming the lamp up?
191. Upon what is the size (area) of a light source dependent?
192. Has a light source diameter greater than one-half inch any screen illumination value?

The Mirror Reflector, page 405

193. What does the mirror used with Mazda do?
194. How is the mirror located with relation to a monoplane filament Mazda?
195. What is the advantage of careful positioning of the mirror?
196. Is it efficient to couple a spherical mirror with a biplane lamp?
197. How is the spherical mirror correctly located?
198. Is the use of a mirror with Mazda advisable?

The Condenser, page 406

199. What is the function of the condenser?
200. Why must the light source be as close as possible to the collector lens?

201. What is the chief function of the prismatic or aspheric condenser?
202. What type of condenser does the newer types of Mazda lamp employ?
203. What kind of surfaces do aspheric condensers have?
204. Through what angle will the aspheric condenser pick up light most efficiently.
205. Do aspheric condensers work best at short distance between the condenser and aperture?

The Projection Lens, page 409

206. Does the Mazda light beam diverge rapidly between aperture and projection lens?
207. What projection lenses must be used where E.F. falls below 4.5 inches?
208. Should No. 2 size projection lens be used when the E.F. is in excess of 4.5 inches?
209. What size screen does Mazda illuminate best?

CHAPTER XIII

THE LIGHT SOURCE

The light source is a subject of very great importance, since it is the base upon which excellence in projection rests.

(1) At present there are only two sources of light available for projection, namely, the electric arc and Mazda. (2) There are several varieties of the electric arc, each of which is different from all other arcs used for projection and (3) each requires different treatment for production of the maximum quantity and quality of light.

(4) The electric arc is formed by charging two carbons with opposite polarities of E.M.F. from the same power source, bringing them into physical contact and again separating them. (5) Physical contact results in the flow of current which heats the carbon particles until they are "volatilized," that is, transformed into gases. (6) These gases form a high-resistance conductor between the positive and negative carbon tips over which current flows. (7) By the action of the heat engendered by the current, a saucer shaped depression is formed on thetip of the positive carbon (called the crater), the bottom or "floor" of which is, in (8) the straight carbon arc, heated approximately to 3,500 degrees Centigrade, about equal to 6,500 degrees Fahrenheit. (9) Except for the high intensity arc this is the highest brilliancy obtainable by heating any known solid substance. (10) Of all substances carbon will withstand the highest temperature before being transformed into gases. It is possible to secure higher brilliancy by combining chemicals with carbon, as will be explained later.

(11) The novice is often puzzled by the fact that carbon tips charged with E.M.F. may be advanced within a very small fraction of an inch of each other without

result. The reason for this is that air, especially if dry, is an almost complete insulator for voltages such as are employed in projection work. Neither 110 volts, or 220 volts can force current through even so little as 1/64 of an inch of air space. No results are apparent (12) until the carbons are brought into actual physical contact, and by that action a conductor of gas resulting from carbon volatilization is set up between them.

Illumination Values

(13) The floor of an electric arc crater gives off illumination in exact proportion to its brilliancy and area. (14) Our best authorities set the illumination values of ordinary old style d.c. arcs at approximately 165 candle power per square millimeter area of crater floor; of the low intensity reflector type arc also at 165 c. p. per sq. mm; of the reflector type high intensity at 400 to 650 c. p. per sq. mm; of the straight high intensity light source at 750 to 800 c. p. per sq. mm. when using a 13.6 mm trim at 120 to 125 amperes; of the old style a.c. arc at 130 c. p. per sq. mm and of the new type a.c. arc at 280 c. p. per sq. mm. These values are not precisely exact, but closely approximate.

(15) It follows that a close approximation of the total candle power of any of the above named arcs may be had by calculating its sq. mm. area and multiplying the result by its candle power per sq. mm. Should you wish to calculate the total candle power (16) first ascertain the area in square millimeters by multiplying the diameter of the crater, in millimeters, by itself, and the product by 0.7854. Multiply the last result by c. p. per sq. mm. of the light source you are dealing with. If you measure the diameter in fractions of an inch, multiply again by 25.5 to reduce to millimeters. This latter is not exact but very nearly so.

The above is of little practical value to the projectionist, but it tends to provide a better understanding of light sources and their relative illumination values.

(17) Without a core the arc would travel around and the screen illumination fluctuate in brilliancy. In Fig. 85

we see a diagrammatic representation of the crater light producing power. In the center it is fairly even, rising sharply at the carbon shell next to the core and dropping

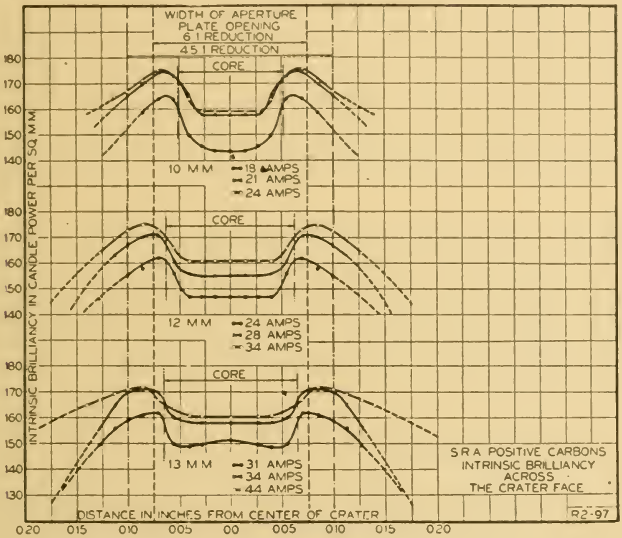

FIGURE 85.

away beyond that point. The central low point represents the illumination of the core.

DEPTH OF CRATER FLOOR

(18) The incandescent film on the floor of arc craters is said by expert authorities to be of tissue-like thickness. It is in fact nothing more than a film. Knowledge of this fact has real value, since a body of carbon of much lower temperature lies immediately back of this incandescent film. (19) If the carbon is underloaded it follows that this body of carbon will be cooler than it would be were the carbon loaded to capacity. All this affects the brilliancy of the incandescent film.

"Cooler" means cooler with relation to the incandescent film covering the crater floor. The body of the carbon is actually white hot, but still much "cooler" than the incandescent film. It presents another understandable reason why a too-large carbon trim is inefficient.

Tail Flame of No Value

(20) It is an error to assume that the light emanating from the arc tail flame adds to the screen illumination. It does yield a bit of illumination where it is very close to the crater floor of the gas body of the high intensity arc. It is quite true that the high intensity tail flame does give off considerable light, but the flame is so located that it cannot possibly be available to the collector lens or mirror to be sent forward to the aperture and projection lens.*

Projector optical trains, viewed as a whole, have two points of equivalent focus: the light source and screen surface. The tail flame may therefore be totally disregarded. (21) It is possibly a hindrance instead of a help, because the light must pass through the tail flame or arc-stream gases.

Shape and Location of Light Source

(22) To obtain maximum results the light source (crater floor) must face the collector lens or mirror as squarely as possible. This requirement is met everywhere except in the old style d. c. arcs. In their case the crater inclines more or less away from the perpendicular. By careful manipulation a perpendicular position, necessary to face the collector squarely, may be approximated even with them.

(23) In lamps in which the carbons lie horizontally, the light source (crater) may be made to face the collector lens or mirror squarely by proper positioning of the negative carbon tip—just enough lower than the positive tip to insure the desired result. (24) The two carbons must of course be in perfect alignment sidewise.

(25) If the crater tends to slope backward at its upper side, then the negative tip is too high. It must be lowered a little. If the crater slopes forward then the nega-

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*In this opinion the Scientific Bureau of the Bausch and Lomb Optical Co. fully concurs. It says: "The projector optical system is designed to focus the crater floor of the electric arc approximately at the projector aperture plane. Any light emanating outside the arc crater is practically useless insofar as screen illumination is concerned."

tive must be raised. If the crater tends to slope sidewise it means the carbons are out of line sidewise.

(26) In explanation of the importance of the crater being made to face the collector squarely, remember that the strongest light flux goes forward straight out from the face of the light source. If the crater floor inclines in any direction away from the center of the collector, then the strongest light flux will go forward in that direction. This is why it is important to position both carbons accurately. Indifferent positioning gives indifferent results.

(27) The light source must not only face the collector squarely, but it must also be located at exactly the correct distance from the collector. (28) Too short a distance may damage or break the collector and, additionally, is a bad optical condition. Too much distance means a loss of light.

(29) In the case of reflector type lamps the distance is fixed by the focal length of the mirror and a very slight error in distance may cause a great loss of light. The length of the arc must be exactly right or the light will suffer. Except in the case of the high intensity arc, its correct length may best be judged by the arc voltage. (30) Ascertain exactly what arc voltage gives the best results on the screen (this varies with the amperage and type of light source) and then maintain that voltage constantly. This method will produce excellent results all other things being equal.

Straight High Intensity Light Source

(31) By "straight high intensity" we mean the high intensity arc with which a glass condenser is used to collect and converge the light. (32) It is by far the most powerful light source used in motion picture projection, running as high as 800 candle power per square millimeter area of light source area. (33) When properly handled the 13.6 mm trim working at 125 amperes should drop very little below 750 candle power per sq. mm. of light source area.

(34) The light source is very sensitive to faults. Light

production falls off rapidly with faulty adjustment or handling. (35) Under proper conditions using a 13.6 mm. carbon trim, the arc will produce a total illumination of approximately 19,000 candle power at 70 amperes. At 100 amperes this is increased to about 40,000 c. p. and at 120 amperes to about 63,000 c. p. These figures represent the total light production. They are quoted merely to convey some idea of the effect of amperage, the rise in brilliancy being fairly steady from 70 to 120 amperes.

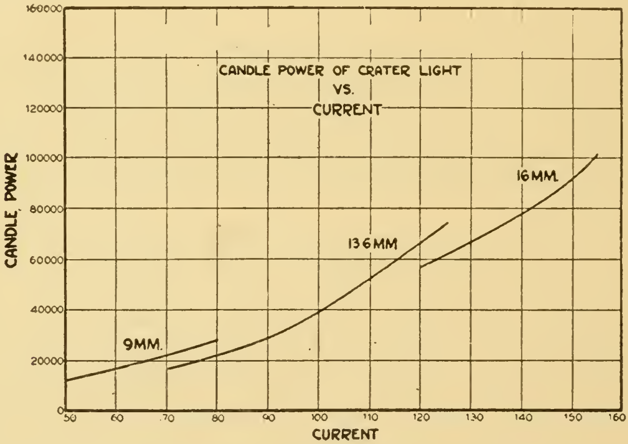


FIG. 86.—Graph shows the candle power of light production compared with the flow of current.

(36) Fig. 86 illustrates a correct high intensity arc adjustment. (37) It is unsafe to be guided wholly by arc voltage in handling the high intensity arc. (38) The light itself is presumed to emanate from the chemicalized incandescent gases contained in the crater. The action is not yet fully understood, (39) but the light brilliancy is far greater than the brilliancy obtainable by carbon incandescence at volatization temperature.

(40) The crater must be kept filled with this gas at all times. If the gas were not confined in the crater it would flow out freely and the high intensity effect would be almost wholly lost.

(41) The confining agency is none other than the stream of electrons emanating from the negative car-

bon, ordinarily termed the negative gas stream or "flame." It performs its work well only when negative carbon tip is located at exactly the right point, as illustrated in Figs. 86 and 87.

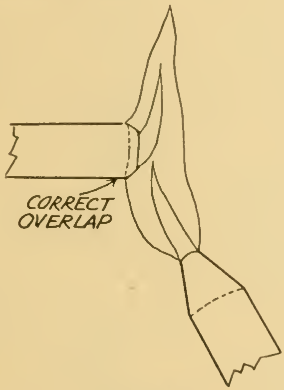


FIGURE 87

(42) The "right point" has been found to be that which will cause the negative gas stream to impinge just a little upon the lower edge of the positive crater.

(43) Fig. 87 shows the exact correct arc gap measurements for a 16 mm positive trim and illustrates the negative position that will cause loss of light and flickering of the arc.

THE STRAIGHT HIGH INTENSITY LAMP

To explain the text that follows we are showing excellent drawings of a popular high intensity lamp. Fig. 89 shows all the important parts. (44) While it is true that lamps vary more or less in constructional details they all perform the same functions and these drawings are a common guide to all lamps, including your own, no matter what its make is.

POSITIVE CARBON CONTACTS

(45) The positive contact parts, AA in Fig. 89, are made exceptionally heavy in all high intensity lamps. They are made of the best heat resisting material known. With proper care they will last from 300 to 400 hours. If, through carelessness or otherwise, these contact parts

are badly burned and pitted (46) they should be discarded and a new pair put in. (47) To try to file them is futile.

(48) If the contact parts are neither burned nor pitted, they may be cleaned. Remove the contact. Wrap a strip of crocus cloth, or lacking that a strip of No. 1 emery cloth around a round steel bar 7/16-in. in diameter. (49) If no such bar is available, use a 7/16-in. diameter negative carbon instead. Rub the contact surface until it is

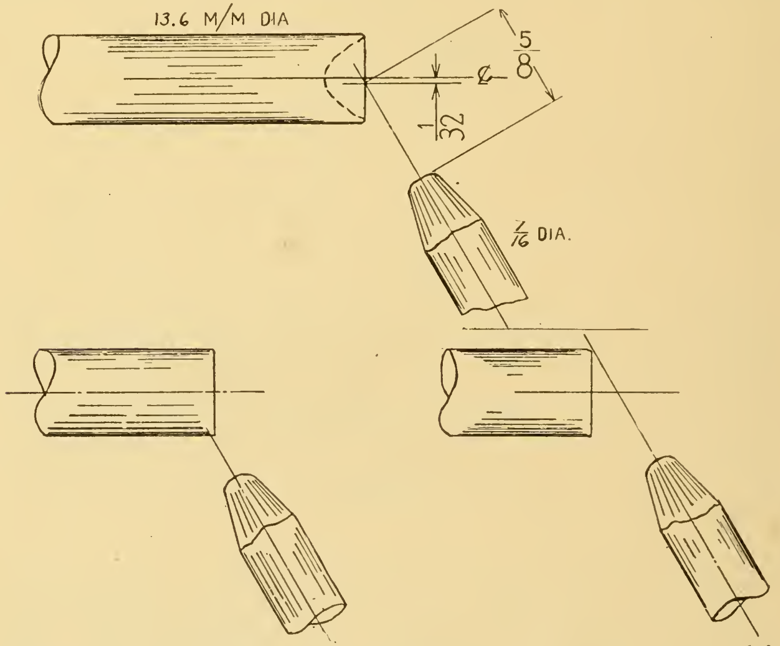


FIG. 88.—Upper illustration shows the correct carbon position. Lower left shows incorrect carbon position resulting in loss of light. Lower right shows incorrect carbon position resulting in a flickering of the arc.

clean and bright. Be sure the surface is smooth. (50) Should any minor swelling of the metal be found it may be very carefully smoothed off with an emery wheel.

It is difficult to keep the carbon contacts of high intensity lamps in good condition yet this is one of the most important items. (51) Under the action of high temperature a coating of oxide forms on the contact surfaces, offering high resistance to the passage of current. This resistance increasingly aggravates the condition, the heat

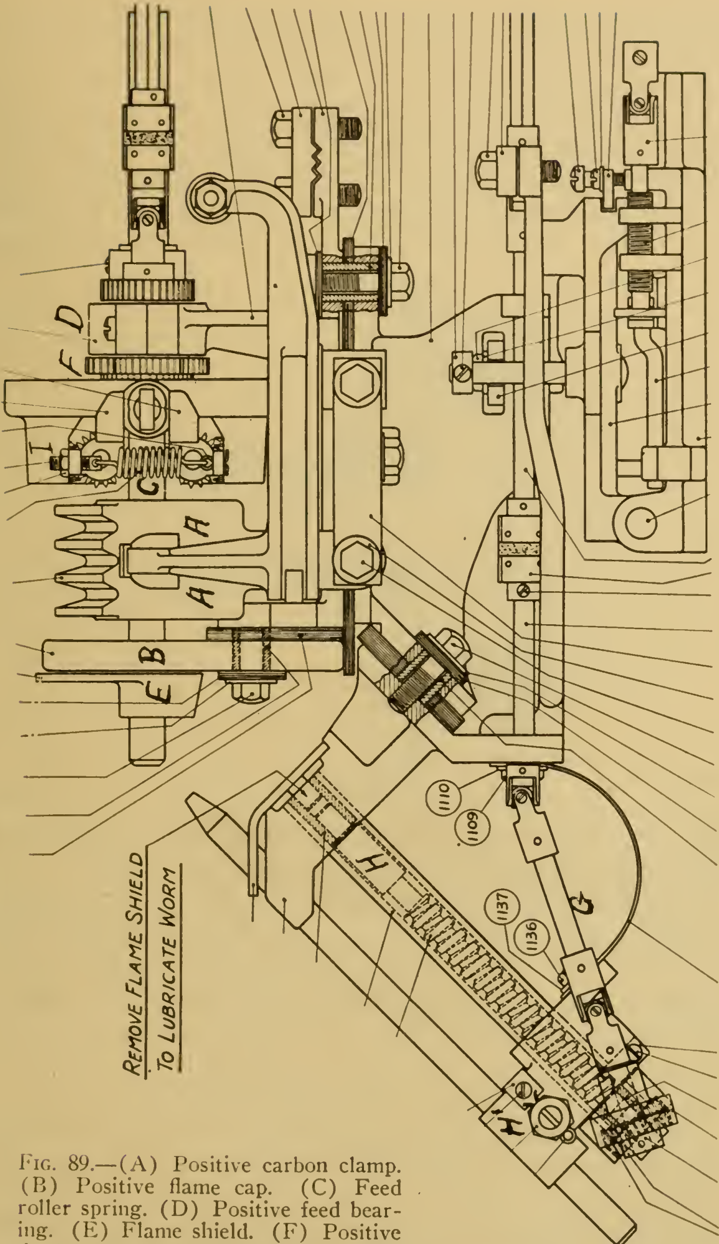


FIG. 89.—(A) Positive carbon clamp. (B) Positive flame cap. (C) Feed roller spring. (D) Positive feed bearing. (E) Flame shield. (F) Positive feed gear. (G) Shaft that drives negative carbon feeding mechanism. (H) Negative feed worm that pulls negative carbon clamp H upward as carbon is burned away. (I) Nut for adjusting feed roller pressure.

generated by the resistance becoming so great between carbon and contact, that the contact metal fuses no matter how "heat resisting" it may be.

(52) This condition demands that the contacts be thoroughly cleaned at least once each day in the manner before described. Some recommend cleaning them only on alternate days, where high current values are not used, but we most emphatically do not regard that as either

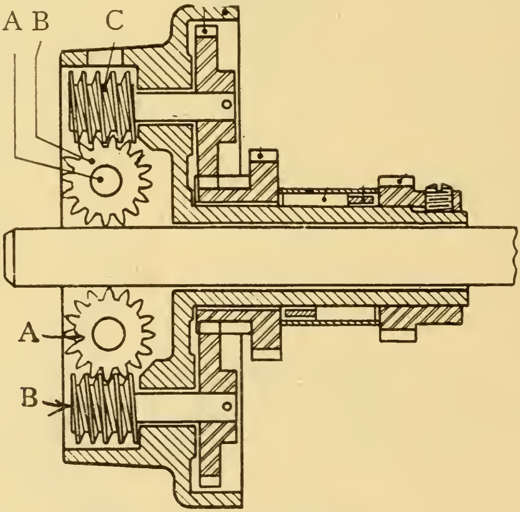


FIG. 90.—Positive feed unit.

good practice or safe. It is no hardship to clean them daily and it provides an added element of safety.

(53) It is wise to have spare positive carbon contacts in stock. Not only is it insurance against trouble, but also it enables the projectionist to install a clean set immediately before the day's run, cleaning the old ones at his leisure for use next day.

POSITIVE CARBON ROTATION AND FEED UNIT*

(54) This part, shown in full detail in Fig. 90, serves to rotate and to feed the positive carbon forward as fast

*All high intensity lamps feed the positive carbon forward at precisely the same rate of speed, and all rotate it at practically the same speed. The methods by which they accomplish the forward feeding and rotation may differ along with many mechanical and electrical details but the basic action is the same for all.

as it is consumed. The entire part rotates, carying the carbon with it, while at the same time toothed wheels A-A, driven by worm gears C-C, feed the carbon forward as it is burned away at the arc. Wheels A-A are held against the carbon by the pressure exerted by spring C as shown in Fig. 89. The tension of spring C may be altered at will by means of nut I, shown in the same illustration.

(55) The entire unit illustrated in Fig. 90, operates in high temperature and so its working parts must be kept well lubricated. We have always recommended a mixture of powdered graphite and kerosene but some lamp manufacturers object, claiming that the graphite binds the parts. That may be true of graphite grease but a well powdered, pure graphite will not bind up the parts and is one of the best high temperature lubricants known to science. A high grade automobile oil is also good. Whatever you use it is important to keep the parts well lubricated. Graphite, if used, must be in powdered form, mixed with kerosene. The kerosene will burn away at once leaving the part lubricated with dry graphite.

When Positive Carbon Fails to Feed

(56) The trouble usually may be traced to rough, pitted current-carrying contacts. Sometimes—but seldom—it is due to faults in the feeding mechanism. The parts must contact the carbon with sufficient pressure to insure its movement. The feeding toothed rollers are held against the carbon by coil spring C as in Fig. 89, the tension being adjustable by nut I.

(57) The tension should be enough to insure certainty of feeding when the current-carrying contacts are smooth and in good condition.

(58) Too much tension wears the parts unnecessarily. It may even cause roughening of the carbon's outer surface, which would weaken the current-carrying contact. Excessive tension may cause "sticking" when bits of carbon, adhering to the outer surface, are forced into the contact. On the other hand too little tension makes for unevenness, or may even stop the feeding completely.

(59) In case the positive carbon ceases to rotate and feed forward, ease up on the contact pressure and try to finish the run. Then carefully examine the contacts for roughness. If they are rough remedy that at the earliest moment or the contact blocks will be ruined quickly.

(60) To make a quick test for roughness, place the lamp in re-trim position, release the feed mechanism and shove the positive carbon backward and forward several times through the current-carrying contact. With the front end of the carbon extending out in normal operating position, and with the feeding mechanism released, you should be able to move the carbon backward and forward easily. If it binds more than it should, then one of two things or both, is the trouble. Either the pressure of the contact blocks is too heavy or the contact surface is roughened. Smooth the contacts and (or) adjust the contact pressure.

High Intensity Carbon Contact Pressure

Too little contact pressure causes arcing and quickly roughened, burned contact surfaces. (61) Too much pressure places undue strain on the feeding mechanism and may cause the carbon to stick—to fail to rotate and feed. (62) There must be good electrical contact between the rotating carbon and its contacts or trouble will result.

(63) Always have spare feeding mechanism parts in stock, ready for use. Ordinarily the controlling spring and parts that contact the carbon are sufficient to have on hand for an emergency.

The Flame Shield

(64) All high intensity lamps have a flame or heat shield plate mounted between the arc and the positive current—carrying contact as a protection against the terrific heat of the arc. In some lamps the hole in this plate through which the carbon passes is bushed with a separate metal part. (65) Neither the hole in the plate or the bushing must be allowed to fill up with carbon dust or oxide, until it reaches the carbon. (66) Carefully

examine the hole before starting the first show each day. Whenever necessary remove the plate or bushing and clean out the hole. (67) Never attempt to operate a high intensity lamp without a flame shield. If a bushing is provided do not run without it in place. It is possible to do so, but the positive carbon will taper back too much and the contact blocks will soon be injured. Keep spare bushings on hand if your flame shields are equipped with them.

The Negative Head

(68) The negative head carries the negative carbon and its feeding mechanism. (69) It must be adjusted so that when the negative carbon tip is raised into contact with the positive it will be exactly central—sidewise in relation to the positive—it must be able to maintain this position until the negative carbon is consumed.

(70) In all lamps the negative carbon is clamped and has its main current-carrying contact several inches below its upper end, but just above this is a sliding loose contact through which the negative carbon receives a portion of its current. (71) The projectionist should see to it that the carbon bears firmly upon the metal of this groove, and that it lies central therein. This last is quite important. (72) If it does not, make whatever adjustment is necessary to line up the carbon properly. The method of adjustment differs with different makes of lamp.

(73) The main points to watch with relation to the negative head are keep the carbon in exact alignment, to keep moving parts (feeding mechanism) well lubricated, and to keep carbon contact clean and tight.

(74) The selection of proper carbon trims, burning them at the most efficient amperage for the trim and maintaining the exact correct position of the negative and positive carbon tips with relation to each other are all vital points, particularly with high intensity arcs.

(75) The high intensity carbon is very critical with regard to current flow, burning below the rated capacity results in a heavy loss in light production and very in-

jurious to light quality. Burning above rated capacity wastes both current and carbons.

Speed of Carbon Consumption

(76) The following approximate speeds of high intensity carbon consumption will enable projectionists within reasonable limits to estimate whether or not a positive carbon stub is long enough to run an additional reel, if the footage of the film on the reel is known. Rated amperage is assumed in each case.

9 mm positive, 4 minutes per inch—15 inches per hour.
13.6 mm positive, 4 minutes per inch—15 inches per hour.

(77) Often stubs of carbon are discarded which might serve for another reel, or at least a short reel, if the projectionist knows just how much time is required to consume each inch of carbon. The above figure may be accepted as correct for rated amperage. If the amperage is changed, the time, of course, will be altered. For example, while a 9 mm carbon will only burn 12.8 inches per hour at 75 amperes, it will consume 22.4 inches per hour at 85 amperes.

(78) We recommend that projectionists record the exact burning time of the positive and negative carbons for one full day. To do so, note the exact time the arc is struck and cut off at each run. When you have finished with the carbons divide the exact number of inches of carbon consumed by the number of minutes of running time—this will tell you what fraction of an inch of carbon is used per minute. Record this information for future use. Remember, if you change either the amperage or the carbon diameter you will alter the amount of carbon burned per minute but it is no big job to compile data covering all amperages used in a given theatre.

(79) The experienced projectionist can estimate current flow fairly well by observing the light source and rheostat settings. But for accuracy use a reliable, properly calibrated ammeter placed where the projectionist may observe it easily. "Guessing" by rheostat

setting, or the appearance of light source is often misleading.

Ventilation for High Intensity Lamps

(80) Heat in the lamphouse is injurious to its wires, insulation and other materials and is very trying to the projectionist. On the other hand too much ventilation makes the light source unstable. (81) It is a safe rule to have all the ventilation possible without disturbing the light source. The projector shutters now used direct a strong blast of air toward the lamphouse and it is well to protect the forward vent holes with a metal shield having an opening at the sides.

(82) Always have the dowser closed when you strike a high intensity arc, but do not keep the dowser down too long while arc is burning unless you want a damaged dowser blade. If the dowser is not down while you strike arc you may get a badly pitted collector lens. The high intensity arc throws off minute particles of incandescent carbon at the instant of striking the arc.

(83) After each reel is run, examine the collector lens or mirror and brush off any ash or dust that may adhere to its surface.

Reflector Type High Intensity Light Source

(84) All that has been said of the straight H. I. light source applies equally to the reflector type H. I. light source. The equipment involved is different in many ways, but the light source is exactly the same, only its amperage limit being lower, (85) its range being from 60 to 85 amperes. In some makes of lamp the negative is carried at essentially the same angle as in straight high intensity light sources. In others the angle is much less.

Low Intensity Reflector Type Light Source

(86) When properly handled this type supplies an amazing amount of very white light per watt of power consumed. (87) First, the light source area is small and therefore well adapted to an aperture of limited dimen-

sions. Second, as compared with types from which light is collected by a thick heavily-curved double-lens condenser, the loss through reflection and absorption is almost negligible. Third, the mirror collects a very large angle of light—that is, a very large percentage of the total light.

(88) The total light production varies with varying amperage, carbon trim, etc., (89) but averages about 165 candle power per square mm of crater floor area. This figure applies to the low intensity arc only. (90) With carbon trims in right relation to the amperage, current flow may vary from a low of 12 amperes to a high of 50 though motion picture projection seldom requires more than 30 amperes.

(91) The average increase of crater area per ampere of added current is about 1.85 sq. mm. This varies somewhat, but is sufficiently accurate to be used in roughly computing the light production power of different amperages. (92) The core brilliancy is fairly uniform, but somewhat lower than that of the crater floor formed upon the carbon immediately surrounding it.

The lamp itself is mechanically simple and easy to handle (93) requiring but a few things to observe in its operation.

Use the proper carbon trim, including carbons of right kind and of correct diameters, operated neither above nor below their rated amperage capacity.

Place the positive carbon in correct alignment with the optical axis of the projector optical train and in exactly central position.

Place the negative carbon in exact alignment with positive, but so located vertically that the crater burns as flat as possible and squarely facing the collector.

Have firm, clean, smooth contact between carbons and carbon contacts throughout entire length of the contact.

The arc control should maintain the arc gap steadily with as little variation in length as is possible. Many projectionists have fluctuating light production either because the arc control is in poor condition or improperly adjusted or because the arc control is badly designed and will function only when unnecessary variation in the arc gap occurs. It is entirely possible to so design an arc control that less than ½-volt variation in arc voltage will cause it to function and feed the carbons forward. Controllers that will not do this should be refused.

Keep all electrical contacts clean and tight. Take loose lugs from the lamp binding posts and clean the contact surfaces with crocus cloth or 00 sandpaper (preferably the cloth) once each week in all-day theatres and once in two weeks in two-a-day theatres. Even if the metal looks clean take the precaution to polish the surfaces with the crocus cloth or lightly with the 00 sandpaper. A thin, almost invisible scale of oxide coating having high resistance power frequently forms, especially if the contact is not set up very tight.

(94) Examine all wires inside the lamphouse frequently. If they feel stiff and springy they are alright. If they do not, slit the insulation, pry the strands apart and examine them. If the interior of the wires is brown instead of copper colored, they are already offering too much resistance to the current flow and should be replaced immediately. Wires that are brown on the outside but still do not bend easily and are copper colored inside (asbestos-covered stranded wire) are still fit for use but should be examined frequently.

See to it that the backing of the collector-converging mirror is in good condition and that its face is perfectly clean and nowhere pitted. (95) It is an excellent plan to wash the mirror each morning while it is still cold. Use strong soap suds, rinse it off thoroughly and then polish. Be careful not to get the back of the mirror wet, as water damages some types of mirror backing.

(96) Mirrors may be cleaned with a fifty-fifty solution of water and pure grain alcohol. Never use wood alcohol or denatured alcohol because it will leave a thin coating on the glass.

Positioning the Mirror

(97) The light source must be at precisely the right distance from the mirror, and the mirror must be exactly

the right distance from the film plane at the projector aperture—not from the cooling plate, but from the film itself.

Even so small an error as the fraction of a millimeter in the distance of the light source from the mirror may reduce the screen illumination, though a small error in the distance of the mirror from the film plane will do no serious harm. It is best to have all measurements exactly right. The lamp manufacturer will supply the exactly correct distances.

To obtain the right distance follow these simple instructions: First, before inserting the carbons, cut a stiff wire exactly the length of the distance the lamp manufacturer recommends between mirror and film plane. Stretch this wire through the carbon clamp openings and with it locate the mirror at exactly the right distance—which will be the length of the wire from the film plane to the surface of the mirror beside the hole in its center, or to the center of the mirror if there is no hole.

Next, cut small copper wires, say about a No. 10, as long as the distance that is recommended between the light source to mirror Install two carbons and burn them until a normal crater floor has been established. Then, after the parts have cooled down, locate the crater where the mirror surface, about 2½" from its center, just contacts the end of the wire all the way around when the other wire end is in contact with the crater center.

By this method the mirror will be very close to correct position, though not exactly. For one thing, the center of the crater floor being the carbon core, it is likely to be depressed below the rest of the crater floor; also the wire end may not be precisely at the crater center.

Next, having set the projector rotating shutter at open position and blocked up the automatic fire shutter, project the white light to the screen (the projector not running), and move the mirror very slightly toward and away from the light source, watch the results upon the screen closely. Make all possible experimental mirror adjustments very slowly and cautiously, until the point is found where there is both maximum illumination and evenness of light distribution upon the screen. When you get that lock the mirror into place. The position of the mirror should be checked at reasonable intervals to make sure that it has not been disturbed.

(98) In the matter of lubrication the projectionist should follow the recommendation of his lamp manufacturer. Not all of them use the same materials for bearings of moving parts. Some demand that no lubrication be applied to any part of their lamp. Other manufacturers suggest lubricating certain parts only, but not all agree on what lubricant is best.

For lubrication of parts working in high temperature we firmly believe that a mixture of pure powdered graphite and kerosene is best. Some lamp manufacturers condemn its use, claiming it clogs up the bearings, but this, we believe, is due wholly to the use of impure graphite or graphite mixed with grease. Graphite-grease mixtures must not be used at all. We suggest that the lamp manufacturer's recommendation be followed implicitly and in the event trouble arises from the use of an improper lubricant, the manufacturer will have to bear all responsibility.

Old Style D.C. Arc

(99) Since this type of light source is now seldom used for theatre projection (because of its poor efficiency it should not be used at all), it is neither necessary nor desirable to deal with it extensively. In these lamps cored carbons of proper diameter should be used, neither over nor under loaded, with the negative tip adjusted so that the crater of the upper carbon will face the collector lens.

New High Intensity Low Amperage Carbon Arc

(100) Prior to the development of the two new high intensity light sources (described later), there existed a wide gap between the highest screen illumination practicable with low intensity reflecting arcs operating on direct current at 16 to 42 amperes at the arc and the lowest

screen illumination obtained with the high intensity direct current arcs using rotating positive carbons and operating at arc currents ranging from 65 to 150 amperes.

(101) This gap not only manifested itself by a wide difference in current consumption, but also in screen illumination. (102) The color of the light from the low intensity mirror arc installations, while appearing a brilliant white when viewed by itself, is actually a yellowish white when compared with light from the high intensity sources.

(103) A careful study of carbon consumption by theatres in this country and Canada showed that approximately 60 per cent of the total fell into the field of low intensity mirror arc operation, and comprised a large percentage of the smaller theatres.

Briefly stated, the above are facts upon which was based research work that has made available to small theatres new light sources providing the same blue-white light that characterizes the screens of the larger theatres, and at sufficiently low expense of operation to impose no extra heavy burden.

(104) This marks a real forward step in projection. It not only raises the standard of screen illumination in the smaller theatres, but also provides a greater comfort of vision to theatre patrons. These new light sources are well worth consideration by exhibitors and projectionists in all small theatres.

(105) Two types of carbons have been designed for these new light sources. First, there is the new, high intensity, copper coated carbon for the alternating current high intensity light source. Second, there is the new, copper coated carbon for direct current, high-intensity, non-rotating, positive light source, popularly known as "Suprex."

The New A.C. High Intensity Arc

(106) This light source is quite different in character from any previously placed before projectionists. It is essentially a development having its base in the ordinary

flame arc carbon. The cores contain the cerium group compounds which, as we already know, supply a very brilliant, white light.

(107) Instead of permitting the arc voltage to increase with increasing current flow, as in the normal operation of the old type flame arc, the voltage, as well as the arc length, is decreased in this new light source, tending to steady the arc and to concentrate the light producing areas into smaller space at the carbon tips, as is shown in Fig. 91.

FIGURE 91

This concentration gives a very brilliant light source, from which the light is collected by a mirror and sent to the projector aperture in the form of a "spot."

Other facts established during the development of this light source are, (108) first, that a much larger quantity of the light can be projected to a screen with a given optical system and aperture plate than with a low intensity, direct current arc taking the same power from the line. Second (109) the color of the screen light is blue-white, resembling very closely that obtained from the direct current high intensity arc.

(110) In addition to this the first cost is less because expensive switchboards and current rectifying devices are unnecessary, these being replaced by a relatively low-priced, highly efficient transformer. The switchboard can be very simple and inexpensive. (111) In addition to all this no ballast resistance is required, eliminating the loss of light so common with the use of ballast re-

sistance. (112) The carbons at present in use for this new light source are made in two sizes. There is an 8 mm diameter carbon for 75 to 80 amperes at the arc, and of 7 mm diameter carbon for arc currents of 60 to 65 amperes. The carbons are copper coated. The same type and diameter of carbon is used in each holder. (113) The carbons lie horizontally, with the crater acting as a light source, facing the back of the lamp and in focus with an (114) elliptical reflector (reflector type lamp) that projects the light picked up from the light source directly to the projector mechanism cooling plate and aperture. (115) The lamps are provided with an automatic feed control that keeps the arc length properly adjusted.

(116) The projectionist must follow the lamp manufacturer's instructions in caring for the arc feed mechanism and the carbon adjustment. This is a point we have stressed many times before because the carbon manufacturer works closely with the lamp manufacturer in the development of light sources for projection and it is difficult to improve in the projection room what they have worked out together over long periods of time.

Amperage and Voltage Rating

(117) Following is a summary of the current and the voltage rating of the National Copper Coated High Intensity a.c. Carbons and their approximate consumption rates.

TABLE NO. 6

	8 mm Carbon	7 mm Carbon
Arc Current (amperes)	75-80	60-65
Approximate Arc Voltage	24-29	23-26
Consumption (inches per hour)	4.0-5.5	4.0-5.5
Current Density (amperes per sq. in.)	970-1040	1000-1090

(118) The high-intensity a.c. light source is essentially a high current-density low voltage arc, as may be seen from the above summary. By high current-density we mean high current (amperage) applied to a small diameter carbon. To calculate current density, divide the current flow, in amperes, by the cross section area

of the carbon in fractions of a square inch. The result is the current density, in amperes, per square inch.

(119) At rated currents the current density of this new a.c. arc, namely, 970 to 1090 amperes per square inch of carbon cross-section, is very much higher than that of direct current low-intensity mirror arc carbons (140-188 amperes per quare inch) and somewhat higher than even that of the high-intensity direct current positive carbons (450-900 amperes per square inch).

Why the Copper Coating

(120) Another difference is that in the conventional direct current high-intensity lamp the positive carbon is gripped at a point close to the arc, whereas in the new a. c. high-intensity arc both carbons are clamped further back. (121) It is therefore necessary to coat the a.c. high intensity carbons with copper to provide proper current carrying capacity without undue heating of the carbon.

The copper coating does not in any way affect the arc stream. Its only function is to furnish a low resistance path for the current from the carbon holder to a point near the arc. (122) The copper coating continuously melts away as the carbon is consumed, so that it is never sufficiently close to the arc to affect the arc stream.

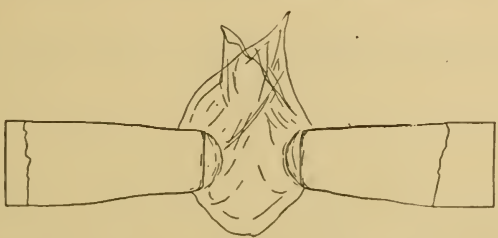


Fig. 92.—8-mm. a-c. high-intensity carbons, overloaded: 90 amperes, 35 volts.

As has already been noted, the copper coat is designed to take care of the current rating of the carbon without undue heating. (123) If the current is too great the copper will melt back too far from the arc, as shown in Fig. 92, whereupon the arc becomes unsteady and is apt to blow out. Moreover, the arc voltage and consumption of the carbons may be increased to such an extent that they will be outside the range and control of the arc-feeding mechanism.

On the other hand if the current is too low, the copper will not melt away as far from the arc as it should, whereupon the light will be very much reduced and neither the current or the voltage will be constant. This condition results in an unsteady arc which "flops" from the top to the bottom of the carbon, as illustrated at A and B in Fig. 93. (124) If the current and voltage limits recommended in Table 6 are carefully observed, the copper will melt away continuously to exactly the right distance, permitting the arc to burn steadily. The illustrations of the arcs known here are all traced from actual arc images. They show the true relationship between the different parts of the arc.

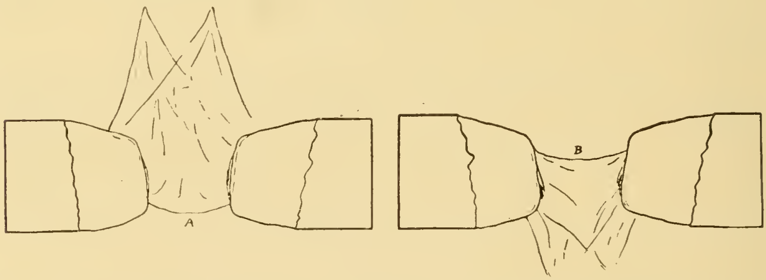


Fig. 93.—8-mm. a-c. high-intensity carbons, underloaded: 60 amperes, 24 volts; showing different positions of the arc as it "flops" about on the ends of the carbons.

(125) It is essential to perfect operation of the arc and good projection light that the high intensity a.c. arc be maintained within certain very definite limits. Figure 94 shows the high intensity a.c. arc burning under good conditions, at 80 amperes and with 25.5 volts drop between two 8 mm carbons.

(126) Both copper coatings end 0.35 of an inch (8 mm) long. The end of the electrode is 0.225 of an inch (5.7 mm) in diameter. There may be some slight difference in these dimensions, due to variations from one trim of carbons, or one lamp to another.

(127) The arc itself consists of a highly luminous gas ball close to each carbon tip and a section of lower luminosity almost the shape of a ball extending an equal distance both above and below the carbon tips, ending at their top in two well defined, short tail flames.

It is interesting to note that the shape of the highly luminous portion of the arc near the electrodes approximates the shape of the intrinsic brilliancy curve across the face of the crater reproduced in Fig. 95. (128) This highly luminous portion of the arc close to the electrode decreases in size as the current is decreased. It becomes very small at the lower current-densities, as illustrated in Fig. 93. The result gives a much lower intrinsic brilliancy curve and less light on the screen.

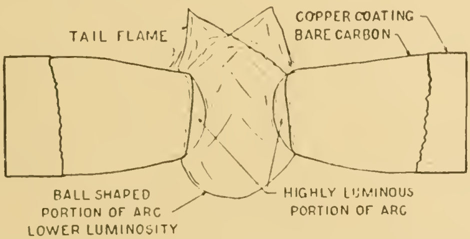


FIG. 94.—8-mm. a-c. high-intensity carbons: 80 amperes, 25½ volts; good operating conditions.

(129) As the arc length is decreased it holds essentially the same shape, if the operating conditions are favorable, until it reaches approximately 0.23 inch (5.8 mm), or 24 volts. At A, Fig. 96, we see the arc just after that point is reached, with a shorter arc length and poor burning conditions. (130) When the arc length is 0.23 inch (5.8 mm) the arc stream begins to be turbulent. The two tail-flames and the highly luminous portion of the arc close to the electrodes lose their identity and the whole arc assumes a boiling and seething appearance, as at B, Fig. 96. As projectionists say, the arc "sputters." There is rapid flicker and the arc and current are erratic. In addition at such very short arc lengths there is a noticeable shadowing effect from the rear electrode itself.

(131) If the length of the arc is increased beyond that shown in Fig. 94, the form of the arc will be sustained, if the operating conditions are proper, until the length is approximately 0.35 inch (8.9 mm). In Fig. 97, A shows the arc immediately before and B after such a point has been reached. At and beyond that length the arc has a tendency to move upward, so that the lower part no longer bows down appreciably and the upper part and the tail-flame become greatly extended. The highly luminous portion close to the electrode likewise becomes distorted as shown at B in Fig. 97 and the arc is unstable to

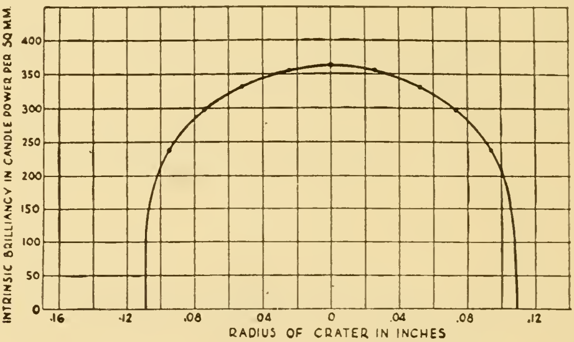


FIG. 95.—Intrinsic brilliancy across crater face; 8-mm. a-c. high-intensity carbons, 80 amperes, 25½ volts.

such an extent that it will repeatedly jump back and forth between the positions shown at A and B in Fig. 93.

(132) Another condition that must be considered, and if encountered, corrected, is shown in Fig. 98. The arc being of medium length would ordinarily have the appearance shown in Fig. 94, but is disturbed by external sources, so that it appears very much as at B in Fig. 97. It has a tendency to snap back and forth between that position and the one shown in Fig. 94, causing variation of the current and voltage, accompanied by flicker and uneven light distribution. This condition may be caused by too strong a draft in the lamp house, by an unbalanced magnetic effect due to a poor arrangement of the current leads, or by any other factor that would tend to distort the arc.

(133) If we assume that the design of the lamp

house, its draft and the arrangement of leads are such as will avoid the above conditions, the 8 mm high intensity a.c. carbons at 80 amperes will exhibit good

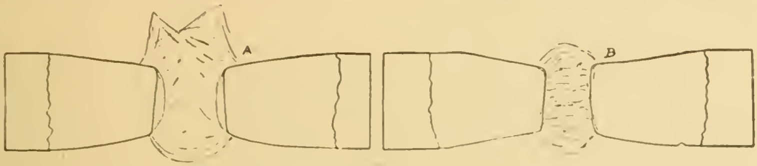


FIG. 96.—8-mm. a-c. high-intensity carbons: 80 amperes, 23 to 24 volts; (*A*) short arc length, good operating conditions (*B*) short arc length, poor operating conditions.

burning characteristics for arc lengths between 0.23 inch (5.8 mm) and 0.35 inch (8.0 mm), and from approximately 24 to 29 volts. There will be a noticeable change of light intensity between those extreme limits, so that the permissible range of variation in arc length and voltage from moment to moment is much less than the complete range of satisfactory performance. This is discussed in greater detail in a later paragraph. The limits of arc voltage, as ordinarily measured at the incoming leads, will vary slightly, depending upon the length of spindle of the carbons, the lengths of the carbons in the holders and the resistance of the holders themselves.

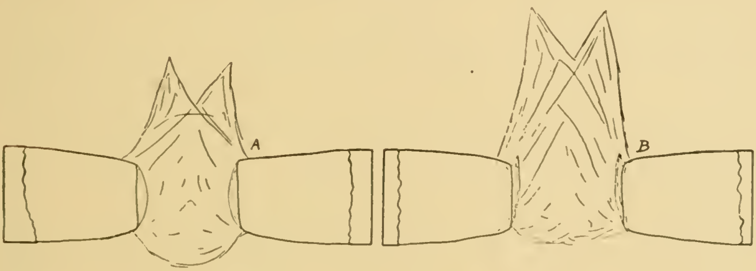


FIG. 97.—8-mm. a-c. high-intensity carbons: 80 amperes, 28 to 29 volts: (*A*) long arc length, good operating conditions; (*B*) long arc length, poor operating conditions.

At 75 amperes the arc lengths that will give good burning characteristics with the 8 mm carbons are essentially the same as those for 80 amperes, but the arc voltage is approximately one volt lower. (134) The 7 mm high-intensity a.c. carbons are rated from 60 to

65 amperes. (135) The corresponding conditions for good operation are an arc gap of 0.21 inch (5.3 mm) to 0.31 inch (7.9 mm), and an arc voltage of approximately 23 to 26 volts.

Limits of Arc Control

(136) The action of the high-intensity a.c. arc under various conditions has a direct bearing on the limitations of the mechanism for feeding the carbons.

From the considerations already discussed it is apparent that such a mechanism must be able to feed the car-

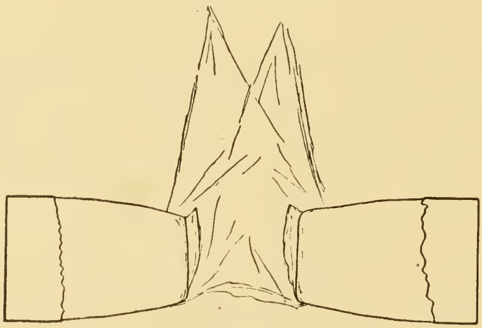


Fig. 98.—8-mm. a-c. high-intensity carbons; 80 amperes, 26 volts; medium arc length, arc disturbed by external forces.

bons at a rate up to 5.5 inches per hour; the rate of feeding depending upon the current passing through the arc. (137) It must also prevent the arc gap from varying more than 0.10 inch (2.5 mm) or (0.12 mm); or in terms of voltage it must prevent the arc from varying over a range greater than 3 or 5 volts for the 7 mm and 8 mm carbons, respectively. These are the outside limits, since in order to utilize the total ranges the mechanism would have to be adjusted so that the average position of the carbons would be exactly at the center of the permissible variation. (138) It must also be borne in mind that if the arc length varies in either direction much beyond the limits of good operation, the current and voltage become erratic and swing through a considerable range. If the feeding mechanism is controlled by either the current or the voltage the above action causes a sudden change in the rate of feeding that is not desirable.

(139) It is not practicable to so adjust the feeding mechanism that it will operate exactly at the center of the permissible range, nor can it be expected that other conditions (line voltage, etc.), would remain sufficiently constand to keep it exactly in that position. It is therefore necessary that the mechanism be designed to feed the carbons within a variation much less than the theoretically allowable limits. The narrower the range the easier it will be for the projectionist to maintain the lamp adjustment within the limits of satisfactory arc operation and so maintain a uniform screen illumination.

These narrow limits for maintaining the arc length presented a real problem, but the desired results have nevertheless been accomplished.

(140) The high-intensity a.c. arc can be operated in series with a suitable resistance unit (rheostat) from the power line, but because of the waste in power involved, a transformer and reactor are used instead. The good transformer has an electrical efficiency of 90 percent or more.

The reactor usually is a transformer with a built-in reactance in the form of a magnetic by-pass. It reduces the line voltage to that required by the arc and by its magnetic by-pass effect will oppose any effort of the arc current to exceed that for which .the transformer has been regulated.

It is desirable that the reactance be kept comparatively low in order that a reasonable power factor be maintained. On the other hand it must be sufficiently high to assure stability of the arc, to the end that it is not extinguished by ordinary air currents when at the longest desirable arc length.

Tests have shown that a 40 percent reactance is sufficient for the purpose. In other words, if the no-load voltage on the secondary is about 40 per cent higher than the load voltage, there then will be sufficient arc stability for all ordinary conditions of work.

True, additional reactance would increase the safety factor, but above a no-load voltage of about twice the load voltage the effect would not be noticeable. A lower reactance could be used with probably satisfactory results in most cases, but the slight advantage achieved would not be worth the risk of possible unsatisfactory performance.

(141) Another important factor in the design of transformers for the high intensity a.c. arc is the possible variation of supply voltage—a condition often met with in theatres. The transformer should be provided either with suitable taps or other means of enabling it to work with the average voltage of the supply lines. Should line voltage vary considerably, some convenient means must be provided by which the projectionist is enabled to make proper compensation and increase the amperage flow in case the drop is objectionable. This may be done by a switch which connects the various coil taps. By its manipulation the ratio of transformation may be changed to meet the requirement.

Fluctuation of Illumination

There has been much argument as to whether or not the new high intensity a.c. arc produces flicker because of the current alternations, with its inevitable low periods of luminosity, while the carbon crater facing the collector lens or mirror is negative.

(142) There is no doubt but there is what is described in projection parlance as "flicker." But it is questionable if the flicker is visible to theatre patrons.

The human eye possesses what is known as persistence of vision, which means that an impression on the eye is retained for an appreciable, though very short period of time. Therefore, if changes in illumination occur with sufficient rapidity, they automatically become invisible to the eye because one period of high light value carries over into the next and partially or wholly obliterates the period of less brilliancy, or even a period of total darkness.

That this is true is proven by the fact that in motion picture projection, for each picture projected on the screen, there are two periods when the screen is entirely without illumination—that is so far as the projection lens is concerned. Yet so far as the eye is concerned it has continuous illumination, without even the slightest visible flicker. The answer is that one light period carries completely over into the next.

In this connection it must be remembered that light is the only thing that may be said to be visible to the eye. Darkness merely means that the eye sees nothing at all. There is no visibility under a condition of total darkness, and only partial visibility under partial lighting. Considering that proposition it is not hard to understand that periods of visibility may carry over through periods of invisibility, and the eye has the illusion of constant visibility, even though there are wide changes in brilliancy. These changes must be rapid to keep the effect of constant visibility.

Through courtesy of the National Carbon Company we are permitted to lay before users of this book certain photographic records of light waves showing the actual brilliancy fluctuations of three projection light sources. (143) Such photographs are known technically as "oscillograms." They are actual photographs of light waves and offer indisputable evidence. The oscillograms should be carefully studied, as they are very thoroughly reliable.

(144) Fig. 99 shows at the top the record of a low intensity 60 cycle alternating current arc. Examine the second line where "1/60 Sec." appears at the left. The "1/60 Sec." shows that one complete current cycle consumes or lasts that length of time, or one alternation half that time, namely, 1/120th of a second. We also see where the dead period lies (jiggles in the V shape lines) and that it is not precisely on the zero line, but alternately a trifle above and below it.

Immediately above we see that the zero axis line is considerably below the base of the needle shape points representing illumination peaks on one side of the current wave, which represent light on the screen—screen illumination at each alternate alternation would perhaps be a bit clearer. We note that the dead period (distance between zero axis and base of illumination peaks) lasts practically as long as do the light periods. The space between the peaks for the old type Low Intensity 60 Cycle Alternating Current Arc shows that a very small amount

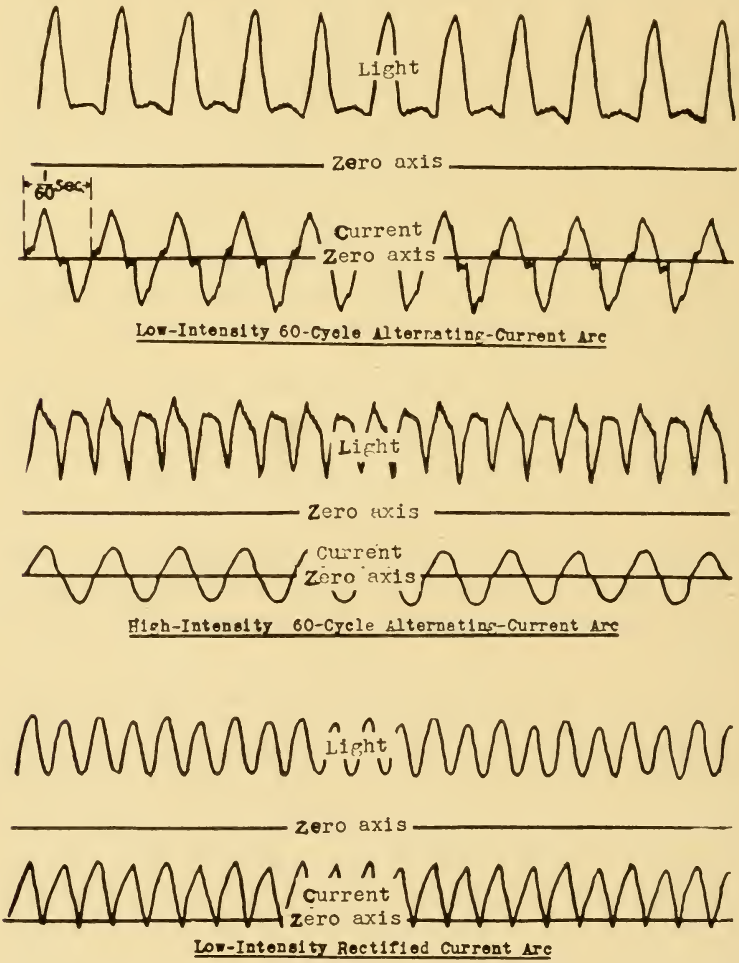


FIG. 99.—Oscilliograms of arc current and instantaneous light on projection screen; projector shutter not running.

of light is supplied by the arc when the current curve is below the axis. This accounts for the much larger and more noticeable flicker from this old type arc, as shown by the top oscillograph curve in Figure 99.

Examining the next, or High Intensity 60 Cycle Arc oscillogram* we note that not only are the light peaks wider (both alternations being shown) but also there is less dead period (distance zero line to bottom of peaks), all of which shows that there is a decided advantage in this type of arc as compared with the low intensity a.c. arc, not taking into account the character of the illumination. It shows, as a matter of fact, a better wave than does the low-intensified arc working with rectified current.

Effect of Shutter

The rotating shutter of the projector has a decided effect, as shown in Fig. 99A. These oscillograms show light in action for screen illumination. Three types of light source are illustrated, two of them a.c. and one that uses rectified current with a two-blade shutter running 1440 r.p.m, which is normal shutter speed at 90 foot projection speed.

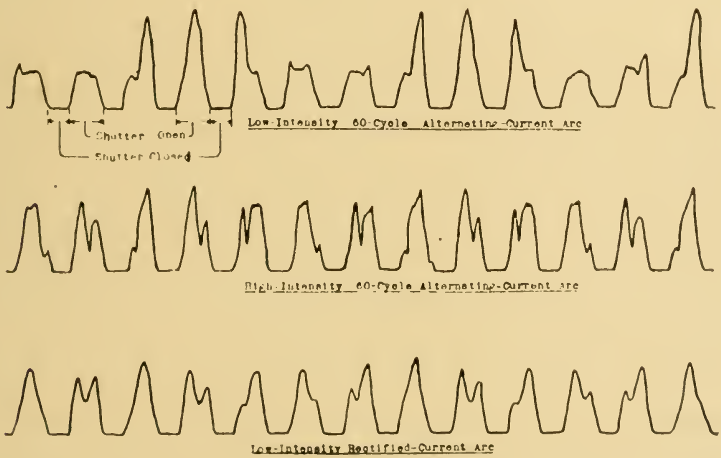


Fig. 99A.—Oscillograms of instantaneous illumination values on a screen. These oscillograms are of the same magnitude as those in Fig. 99.

The variation in peak heights will doubtless be difficult to understand. In the 60 cycle low-intensity a.c.

*In all oscillograms shown in Fig. 99 the projector was not running, hence any effect set up by the rotating shutter is absent.

arc as pictured in Fig. 99 the short horizontal lines at the bottom of the peaks represent the period of time all light is shut off the screen by the shutter blades. The high peaks represent the period the shutter is open and the light coming from the light source at the time it is positive. The low ones represent the light when the shutter is open and the light source (carbon crater facing the collector) is negative.

Engineers of the National Carbon Company recently published a careful explanation of this technical problem and its value to all projectionists is so great that we are here reprinting it in full.

"The effect of the light-wave is very noticeable when the shutter mechanism is operating. The speed of the shutter is fixed at 1440 r.p.m., by the standard film speed of 90 feet per minute. On the other hand, the current from the ordinary 60-cycle circuit, or from a single-phase rectifier placed in the circuit, goes through a characteristic change 3600 times per minute. In other words, the time of opening of the shutter does not correspond to an even number of changes in the current or the light on the screen. This is illustrated very clearly by the oscillograms in Fig. 99A, which show the variation of the light intensity on the screen for the three types of arc with the shutter running at approximately 1440 r.p.m. If it were possible to run the shutter at 1800 r.p.m., which would correspond to a film speed of 112.5 feet per minute, the shutter openings of the ordinary two-bladed shutter would correspond to one-half a cycle in the current and light curves, and would give the same amount of light on the screen for each shutter opening. Theoretically and actually, with a two-bladed symmetrical shutter operating at a speend of 1800 r.p.m., there would be no fluctuation of the light on the screen that could be detected by the eye, even without film in the projector. In other words, the more nearly identical in amount and wave-shape the light on the screen is during each shutter opening, the less discernible would be the fluctuations or beats in the light on the screen.

"It can be seen in Fig. 99A that the amount of light on the screen from one shutter opening to the next varies enormously in the case of the low-intensity a-c. arc. This is due directly to the fact, as illustrated in Fig. 99, during the half cycle that the carbon in focus is negative, the light remains at a comparatively low value. On the other hand, the light from the high-intensity a.c. arc, although of irregular wave-form, is much more nearly constant for each shutter opening, and corresponds much more closely to the curve of the light obtained from the d-c. arc operating on rectified current with the shutter running.

"This is the reason for the very decided improvement in steadiness over the low-intensity a.c. arc, and for the practical elimination, under favorable conditions, of noticeable fluctuation in the light on the screen from the high-intensity a-c. arc. In other words, the light-curve of the high-intensity a.c. arc, being of nearly the same intensity during each half of the current cycle, has practically the same fluctuation characteristic as that of the low-intensity d-c. arc operated by a rectifier. The practical proof of this is obtained by observing the projection of the same amount of light from the three types of arcs with the shutter running. This has been done in the laboratory with a very high degree of illumination on the screen and without film in the projector. Observation under such conditions agrees with the conclusions arrived at from the oscillograms; namely, that the light beat or fluctuation of the high-intensity a.c. arc is very much less than that of the low-intensity a.c. arc and of essentially the same magnitude as that of the low intensity d.c. arc using neutral cored carbons and operated by a rectifier.

"From the standpoint of practical projection, the beat or fluctuation of light is so small that under reasonable conditions it can not be considered detrimental to the quality of the picture. This was demonstrated at a recent meeting of the S.M.P.E. Projection Practice Committee, when pictures were projected by a high-intensity a.c. arc. One member of the Committee remarked at the time that if he could not see the light-beat or fluctuation, it was not there so far as he was concerned."

Low Amperage Non-Rotating Carbon H. I. Arc

For the past decade the great majority of projection arc light sources have been of two types, namely, (a) the high intensity, both straight and reflector type, and (b) the low intensity arc, which is an arc the carbons of which operate at low current intensity. (145) By current density is meant the amount of current flowing per square inch of area.

The high intensity arc carbons considered heretofore all had a relatively large diameter (9 to 13.6 mm positive) with a shell of pure carbon and a core of carbon intermixed with a binder and elements known as the "rare earth groups." These carbons were operated at from 65 to 130 amperes, according to their size, giving a high current density and providing a very brilliant blueish white light.

The low intensity arc used a carbon from 10 to 14 mm in diameter and was operated at from 15 to 40 amperes. This meant low current density as compared with the high intensity arc carbons, and did not produce so brilliant a light per square mm of light source area. The light lacked the blue-white radiance provided by the high intensity arc.

The new, non-rotating positive d.c. high intensity arc uses a very much lower amperage than does either the straight or reflecting type high intensity light source, but its carbons, nevertheless, have high current density and its light is quite brilliant.

(146) This is due to the relatively small diameter of the carbons (6 to 8 mm), operating at from 35 to 65 amperes. Moreover a greater percentage of the total light is available to the projection lens by reason of the fact that the light source area is smaller, and that is a very important point when we are considering a light source from which the beam must be passed through an aperture of restricted size.

(147) Several elements must be considered in determining screen illumination, namely, the brilliancy per unit area of the light source; the total area of the light source; the percentage of the total light collected and passed on to

the spot; the percentage of light at the spot that falls upon the aperture opening; the percentage of light beam on projection lens side of the aperture that enters the lens and the percentage of light that is cut off by the rotating shutter.

In this discussion we are interested only in the fact that in the new arc the crater (light source) has a small diameter and therefore a much greater percentage of its total light will pass through the projection lens. This will be better understood by studying the optical section of this book. The data concerning Suprex carbons will be found listed under Carbons.

(148) As we all know, the high intensity arc produces higher unit area of brilliancy. It is the only method known by which any considerable increase in d.c. screen illumination over that supplied by the low intensity arc may be obtained, save only the high amperage old-style straight arc which did deliver brilliant screen illumination but consumed very much more power.

(149) Heretofore the 9 mm diameter high intensity carbon was the smallest made and it required at least 70 amperes of current to produce satisfactory results. The chief difference between the light source we are now discussing and other light sources is that it is a high intensity arc using small diameter carbons and operating at low amperage, but (150) at current density approximately equal to that of the larger diameter high intensity carbons.

While it is quite true that the light from these new small diameter high intensity carbons per unit area approaches that of the larger high intensity carbons in brilliancy, still the total output is considerably less because the carbon has a smaller diameter and therefore a reduced light source area. As before related, however, a greater percentage of it will reach the projection lens. Other relatively unimportant items tend to aid in rendering this light source very efficient.

(151) For example, the carbons being copper coated, much of the current passes from the contact to a point close to the crater through the copper instead of through

the body of the carbon, thus avoiding heating the carbon by resistance. This has two other advantages. Since the positive is non-rotating, the contact clamp may be placed back a considerable distance from the crater. It may be a plain clamp, thus eliminating the machinery for operating a sliding contact and rotating the carbon, giving the mechanism great simplicity. Again, were all the current to pass through the body of the carbon, it would heat progressively toward the crater, developing a tendency to spindle-burn to a long, tapering point.

(152) As was noted before the crater of the high intensity arc light source must be cup-shaped and deep and of even height at all points so that the luminous gases generated therein by volatization will be retained. The gases are held in the crater by the impact of the negative gas stream.

This stream or flame must be at a slight angle to the face of the positive crater so that all surplus gas is compelled to leave the crater in an upward direction. When the negative is wrongly positioned the surplus gas escapes at various points on the rim of the crater, resulting in an unstable arc and poor screen illumination.

The proper condition is established in the regular high intensity arc by placing the negative carbon at an angle to the positive. (153) In the non-rotating carbon high intensity arc both carbons are centered on the axis of the optical system, hence lie approximately in horizontal position, but in order that the negative gas stream may strike the positive crater at the desired angle, the negative is located with its center a trifle lower than the center of the positive carbon. The action of the gas stream is then aided by forcing it upward by means of a magnet, because an electric arc is influenced by magnetic force.

Carbons in Line

(154) While the negative must be a trifle below the positive, both must otherwise be in exact alignment with each other. If they are not the crater lip will burn unevenly giving poor illumination.

(155) Extreme drafts of air, particularly those caused by projector rear shutters, passing through the lamphouse disturb this type of arc. Where rear shutter blades have vanes to force the draft, the front vent holes of the lamphouse must be either well protected or closed. Some lamp manufacturers recommend the removal of the vanes, but that is merely robbing Peter to pay Paul since it increases the heat at the projector aperture.

(156) It is quite possible to protect the front lamphouse vent holes from such air currents as the rear shutter sets up. Make a metal trough of sheet metal, preferably russia iron to cover the lower holes, the trough having opening at the sides, with a protecting flap bent backwards at the ends, and another at the top, opening upward and back. It is a very simple device and requires only a tinner's shears and an hour of time.

(157) The Suprex carbons used in this light source are made in three diameters, each having a definite current range. Do not attempt to either over-load or under-load them. The 6 mm positive and 5 mm negative combination operates at from 34 to 40 amperes within an arc voltage of 29 to 31; the 7 mm and 6 mm unit operates at from 42 to 50 amperes with an arc voltage of 30 to 34; the 8 mm and 6.5 mm unit operates at from 55 to 65 amperes with an arc voltage of 36 to 40.

(158) In the opinion of competent authorities this light source, when efficiently handled, will produce a very much higher screen illumination per watt of applied power than the low intensity lamp. While it is still impractical to secure more illumination at the screen center with the 8 mm trim than with the 7 mm trim, there is this important difference: the 8 mm trim will supply higher illumination at the edges of the screen image than the trim of smaller diameter, and thus often gives the effect of even illumination over the entire screen area. The total light production is far below that of the rotating carbon high intensity light source but in conjunction with a specially devised optical system it is highly efficient.

(159) In addition to maintaining a straight, even

crater lip and avoiding air drafts, there is another important element—the distance of the arc crater to the vertex of the reflecting mirror. There are three predominant light tones in all high intensity light sources. The carbon shell, being pure carbon, emits light that has a tinge of amber or yellow. Directly in front of the crater floor is a brilliant, pure white gas ball, and in front of this, toward the negative carbon tip, is bluish illumination less intense than that of the gas ball.

The beam of light sent forward to the projector aperture contains all these colors, but (160) they are separated, following each other in the order named. Which of them will be focused at the aperture, and therefore at the back conjugate foci point of the projection lens, depends upon the adjustment of the light source with relation to the reflector. To focus the white light—the best light—at the film plane demands that the positive crater be placed at just the proper distance from the reflecting mirror.

(161) To bring this about the feed mechanism of the lamp must function very accurately. After striking the arc and permitting it to settle down, the projectionist should make the adjustment carefully and correctly. Indifferent adjustment will cause a change in the color or tone of the screen illumination.

Crater Image

(162) To help maintain adjustment project an image of the side of the arc on some surface upon which its correct position can be marked. Do this as soon as you have determined the best crater position and continue to keep the crater rim exactly at that point.

Carbon Feed

(163) In all high intensity arcs the burning rate of the positive carbon exceeds the negative as current flow is increased. For this reason it is necessary that the negative carbon have a separate feed mechanism by which means the projectionist can compensate for the difference. Without this means of adjustment, though the car-

bons will burn evenly at any given amperage, the carbon trim will need frequent hand adjustment at other amperages. Before a high intensity lamp is purchased, the projectionist should make sure it has a separate feed mechanism for the negative carbon.

(164) The current rectifying device employed for

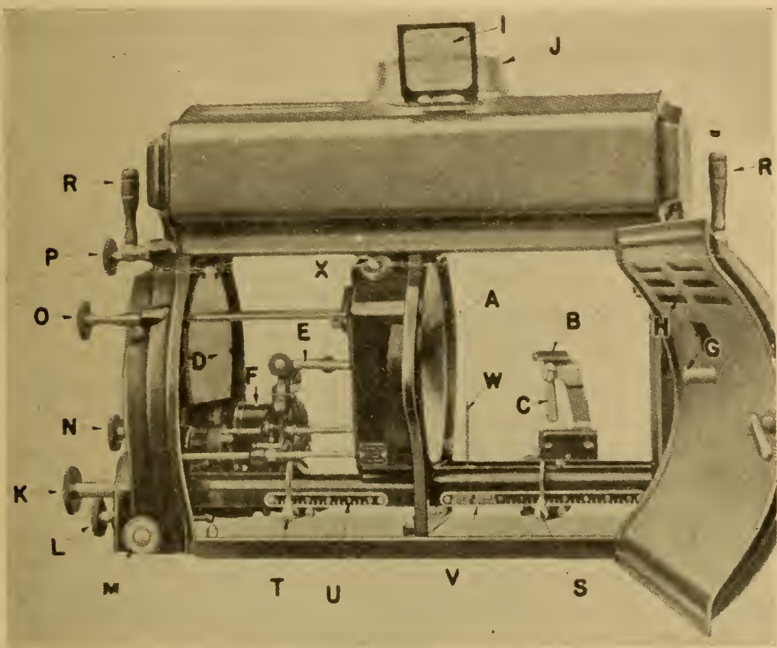


FIG. 99B.—(A) Mirror Reflector. (B) Positive Carbon Jaw. (C) Positive carbon clamp. (D) Separate Negative carbon feed adjustment. (E) Negative carbon jaw. (F) Feed motor. (G) Arcoscope lens. (H) Door ventilators. (I) Arcoscope screen upon which image of arc is projected by lens G. (J) Vent pipe opening. (K) Positive carbon hand feed knob. (L) Arc focusing knob. (M) Arc striking knob. (N) Negative vertical adjustment. (O) Mirror horizontal adjustment. (P) Mirror vertical adjustment. (R) Dowser and flame shield handle. (S) Positive carriage quick return handle. (T) Negative carriage quick return handle. (U) Negative carbon feed scale. (V) Positive carbon feed scale. (W) Arc centering indicator. (X) Arc stabilizing magnet.

serving this type of light source should be set to deliver a rather flat current curve. Too much a.c. ripple in the current is harmful. (165) A single phase rectifier delivers a highly objectionable ripple which renders the arc unstable. (166) A two or three-phase rectifier, motor generator, rotary converter or straight power line d.c. are all acceptable as good current rectifying devices for this type of light source.

In Fig. 99B, we have a view of a Brenkert H non-rotating positive carbon lamp. The carbon clamps are much like those of the low intensity lamps. The negative carbon is movable, up, down, or sidewise, to permit adjustment of alignment. A small magnet sits just above the forward carbon clamp. It has just enough strength to influence the negative gas stream or flame to operate at maximum efficiency. The mirror is eliptical and designed to project a beam that will just fill a projection lens of 2.2 speed. There is a negative feed separate from the positive carbon feed.

Mazda Lamp Projection

Incandescent lamps are still being used successfully for motion picture projection in many theatres, and in schools and public auditoriums. (167) They possess such advantages as cleanliness, low cost of operation, minimum fire hazard and are free from hot lamphouses and the gases generated by carbon arcs. They are simple and once adjusted give little trouble. (168) Their effectiveness in screen illumination, when used in conjunction with good optical system may be compared favorably with illuminants consuming considerably higher wattage.

(169) Mazda screen illumination is characterized by a very agreeable softness with none of the harsh brilliance of light that comes from the high intensity electric arc. (170) Mazda is not sufficiently powerful to show color pictures to their best advantages. Color engineers tell us there is a considerable loss in color values, especially in the blue range.

(171) Mazda lamps employed for projection possess characteristics quite different from those used for general lighting. Projectionists should have a good knowledge of their character and limitations and know what optical systems may be used.

General Characteristics

(172) The Mazda lamp produces light as the result of heat generated by the resistance which opposes the flow of an electric current through a high resistance metallic lamp filament. (173) This filament is of Tungsten wire, because Tungsten has the highest melting point of any known metal. It may be raised to a very high temperature, hence produces the whitest light, as well as the greatest amount of light per watt of applied energy of any material available for such purposes.

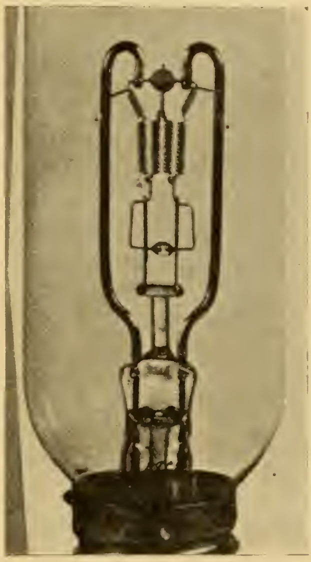


Fig. 99C Monoplane type

The filament is enclosed in a glass bulb which serves to prevent chemical action between the white-hot wire and the oxygen contained in the air. Were the filament in contact with this oxygen it would burn out almost immediately. (174) Lamps employed for projection service are filled with a chemically inert gas, as nitrogen or argon, which serves to retard the burning away or evaporation of the Tungsten, thus either prolonging the life of the lamp or enabling the production of more light at the expense of a short lamp life.

The average life of an incandescent lamp at any given voltage or current flow can be controlled, within relatively wide limits, by design. (175) The lamps that are built for theatre projection service last an average of 100 hours; in some instances this is dropped down as low as 50 hours. In effect this means that the current flow has been fixed at a level which allows Mazda projection lamps 100 hours of useful life or 50 hours, as the case may be. Lamps for portable projector service are designed for an average life of from 25 to 50 hours.

(176) There are several outstanding characteristics of Mazda projector lamps that serve to distinguish them from Mazdas for other illumination purposes. The coils of filament wire are arranged to secure the highest concentration of light, as in the "monoplane" type illustrated in Fig. 99C. By this arrangement most of the light output of the lamp is available to the projector optical system. It produces more screen illumination per watt of electrical power. (177) The additional coils of the "biplane" type, shown in Fig. 99D, doubles the current consumption (wattage), so that biplane lamps not only require increased space inside the bulb, but consume more power, produce more heat and therefore demand increased lamphouse ventilation. (178) Within defined limits the length of the filament wire determines the voltage that may be applied to a lamp and the diameter of cross-section of the wire determines its amperage capacity. The monoplane type is used in conjunction with the mirror shown in Fig. 99F.

(179) Other things being equal it is better to connect the lamp directly to a 115-volt line. However, it has been found that the light source area can be reduced by using shorter filaments of a greater cross-section area which, of course, allows low-voltage lamps. These are the lamps used in theatres where voltage reducing devices such as transformers or resistors may be employed. They are designed for low-voltage and heavy current duty and fill a greater light intensity per unit area of the light source

than lamps of 115-volt rating of the same wattage capacity. With portable projectors, where the bulk and weight of the current controlling equipment is important, "line" voltage lamps are employed.

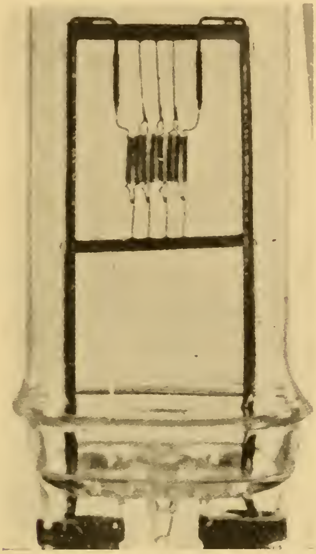
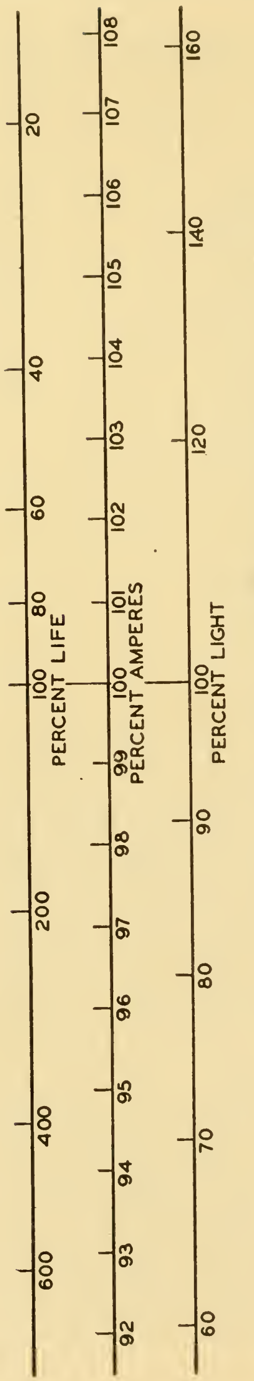


Fig. 99D Biplane type

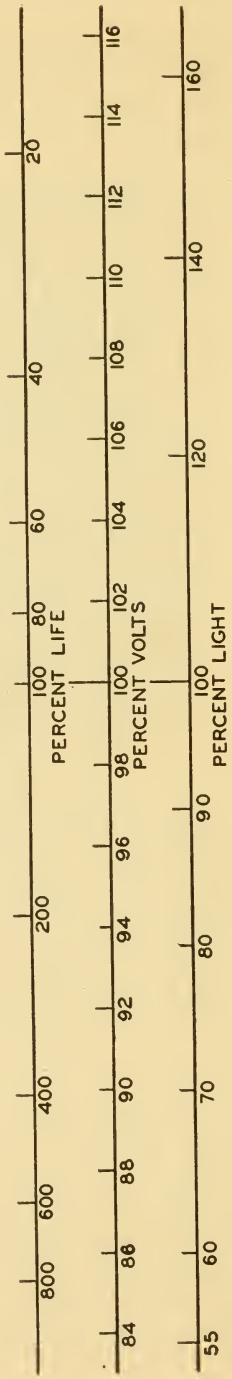
(180) The share of the total light a condenser collector lens of given diameter will pick up depends largely upon the distance of the light source from the collector and the diameter of the lens itself. This is exemplified in Fig. 42. In order to reduce this distance as much as possible and thus increase the angle of pick-up, projection lamps are made with bulbs of the smallest permissable diameter.

The Long Bulb

(181) To secure enough space inside the bulb for the wattage consumed, Mazda projection lamp bulbs are made somewhat longer than at first glance seems necessary. The extra bulb length serves another purpose: The extra space is all above the filament and it is in this upper portion of the bulb that the blackening (tungsten deposit from the filament) takes place where it does not interfere with the passage of light.



Variation of light and life with change of current.



Variation of light and life with change of volts.

FIG. 99E.—These charts represent the effect of overloading. Center line of upper diagram shows that if the lamp operates at only 92% of its normal rating, its life will be increased about 625% and its light power decreased to little more than 60%. If the load is 8% above normal the life of the lamp will be a little under 20% but the light power will jump to over 160%. The lower chart may be analyzed the same way.

(182) Some Mazda projection lamps are designed to operate at constant voltage, others at constant amperage. Both types present advantages but a lamp designed for constant voltage operation will not give its best performance when at constant current, nor will a constant current lamp function at its best at constant voltage.

(183) The older types of theatre projection lamps like the 900-watt, 30 ampere unit, were designed to burn at constant amperage. As the filament burned away the cross-section area was reduced which in turn caused the filament to burn brighter gradually. This increasing brightness was compensation for the blackening of the bulb opposite the filament and more or less, maintained an even screen illumination.

(184) Some of the newer types of Mazda projection lamps contain a small amount of granulated tungsten powder inside the bulb. When the interior of the globe begins to blacken it is only necessary to remove the lamp from its socket and, holding it upside down, shake the lamp until the powder has scoured off all the deposit. Projectionists using lamps thus equipped should at regular, not too infrequent intervals of time, remove the lamp and scour off any deposit that may be on the interior of the bulb.

(185) The life of a Mazda lamp and its light output is very sensitive to variation in rate of voltage or amperage. Fig. 99E illustrates the effect of departing from rated values. Projectionists should be very careful to operate their lamps as close to the values marked on the bulb as is possible. (186) A Mazda projection unit is capable of producing a relatively high screen illumination for the wattage consumed, but it must be remembered that the wattage is low.

Here again the accurate alignment of the light source and condenser with the aperture and projection lens is imperative. (187) The figures following show the extent to which screen illumination is reduced when the alignment of the light source is inaccurate. One hundred per cent projection values are to be obtained only when the filament is centered on the optical axis. Here is an indication of what happens when the filament is off center.

Filament out of center up or down
1/16 inch, loss 96.0%; 1/8 inch, loss 95.3%; 3/16 inch, loss 66.6%
Filament out of center sidewise
1/16 inch, loss 92.8%; 1/8 inch, loss 76.2%; 3/16 inch, loss 57.7%

In the above tabulation we see that if all other optical train elements are in correct alignment, but the lamp filament is, for example, 1/8 inch too high or too low, almost 15 per cent of the light is lost; if it is 3/16 inch too far to one side, almost 43 per cent of the light is wasted which emphasizes the importance of centering the lamp filament exactly on the axis of the optical train.

(188) The majority of the high wattage projection lamps show a certain amount of coil distortion (sagging) towards the end of life. If allowed to continue it may result in a short circuit in the coils. Filament sag cuts down the illumination on the screen or it may cause the lamp to burn out immediately. It is best to replace such lamps to avoid trouble during a performance.

(189) Throwing the full operating load directly on these high wattage, heavy current projection lamp filaments often causes some distortion of the filament. (190) To offset this most lamps have an arrangement that permits them to be burned at reduced current until the filament warms up. In 10 to 15 seconds the various parts of the filament warm up to the same temperature and then it is safe to give it the full current load.

Properties of the Component Elements

Since the standard professional projector aperture and projection lens present openings of considerable size, a light source of generous area can be used. (191) The maximum size of the light source which can be employed effectively with a given optical system is dependent upon (a) the diameter of converging element of the condenser and its distance from the aperture; (b) the size of the aperture opening; (c) the diameter of the projection lens

FIGURE 99F

and (d) the distance of the aperture from the condensing and the projection lenses.

Examination of the curve in Fig. 99G shows that in a typical incandescent lamp optical system the screen illumination increases with the increase in the area of light source up to one-half inch square. (192) More than that merely adds illumination to the cooling plate without raising the screen illumination to any appreciable degree. Therefore the light source area cannot be increased beyond the limits of one-half inch square for the 35 mm projector optical system with any beneficial effect. The newer lamps produce additional screen illumination only because more filament has been included within the usable one-half inch area.

MIRROR REFLECTOR

Mazda lamps of course emit an equal amount of light in a direction opposite to that of the condenser. It is desirable to make use of as much of this light as is possible. (193) This has been accomplished by locating a spherical glass reflector pictured in Fig 99F behind the lamp. This mirror reflects from 80 to 85 percent of the light incident upon its surface and the greater part of the light is brought to a focus in the plane (or planes) of the filament, in the form of an inverted and reversed image of the filament. (194) In the case of the monoplane filament the mirror is positioned so that the image of the filament dovetails with the filament coils, as shown in Fig. 99I. With the mirror adjusted in this way, most of the reflected light flux merges with the beam from the filament coils and passes on to the collector lens.

(195) Two important advantages result. First, the

screen illumination is increased from 50 to 75 percent more than is delivered by non-mirror lamps. Second, the source becomes in effect a solid luminous rectangle which gives a greater uniformity of screen illumination.

Since the biplane filament light source substitutes actual coils of tungsten wire for those formed by the mirror, it might at first appear that the spherical reflector is of little advantage. (196) However, examination of the biplane flament from an angle of forty-five degrees on either side, shows several openings through which the mirror can project light to the condenser. Furthermore, the energy redirected back to the source, raises its temperature without expenditure of current and thus, to some extent increases screen brightness. As a matter of fact it

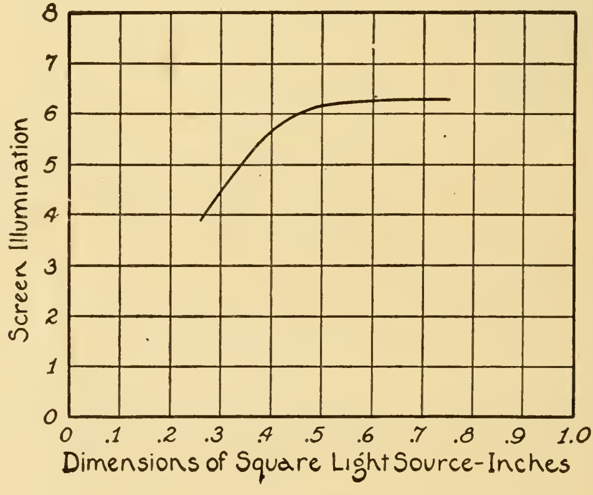


FIGURE 99G

has been found that the use of a spherical mirror with a biplane lamp increases the illumination of the screen very considerably.

MIRROR ADJUSTMENT

Adjustment of the mirror so that its beam falls exactly in the right position on the biplane filament is not as simple as in the case of the monoplane lamp. (197) The mirror should be moved backward and forward until the image of the source, as seen on a card held in front of the projection lens, is exactly the same size as is the source itself. The image is then moved laterally and (or) vertically until it exactly covers the source. Then, and only then, is it ready to deliver maximum results.

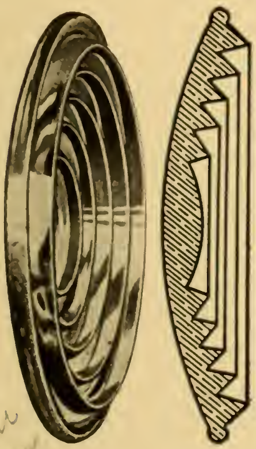


FIGURE 99H

Biplane lamp manufacturers intend that a spherical mirror be used in conjunction with their units. They make proper allowance for the higher temperature of the filament caused by superimposing the mirror image upon it. (198) Failure on the part of the projectionist to use a mirror means only that he is satisfied with inadequate illumination of his screen.

CONDENSING LENSES

(199) As related in detail elsewhere, the function of the condenser is two-fold. It collects the greatest possible share of the light emitted by the light source and converges it upon the projector cooling plate and aperture. The part that falls upon the cooling plate represents unavoidable loss provided the spot upon the cooling plate has the smallest diameter consistent with good screen results. If it is larger than necessary there will be a constant, heavy, wasteful loss. See Fig. 31.

Since the light comes from the source in the form of diverging rays, and that portion picked up by the collector lens is a cone having the light source area as its point and the diameter of the collector lens as its base, (200) it is evident that the greater the diameter of the collector lens and (or) the closer the collector is to the light source, the more light will be intercepted, picked up and sent forward to the projector aperture. (See Fig. 42.)

As has already been indicated, the tubular bulbs of

Mazda lamps are made as small as possible so that the light source (filament) can be placed as close as practicable to the collector lens and in which position, we repeat, the greatest possible amount of the total light emitted will be available to the lens.

Prismatic Condenser

(201) The chief use of the aspheric condenser is in considerable measure to correct spherical aberration. As all projectionists understand the two plain, uncorrected lenses used in the plano convex condenser produce heavy spherical aberration, because each zone (the distance from optical axis) focuses rays at a different distance from the lens than do other zones. The further from the axis they are the nearer the rays are focused to the lens. The rings pressed into the prismatic lens serve to correct this trouble to a considerable degree, and focuses all rays at approximately the same distance from the lens.

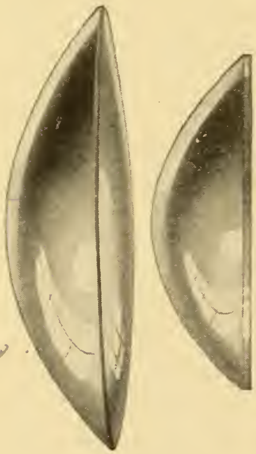


Figure 99I

The older type of Mazda was operated with a 2-lens plano convex condenser. The newer types use either (202) the prismatic condenser shown in Fig. 99H or the more efficient aspheric lens.

The prismatic lens is a pressed lens which in the very nature of things cannot have as true and optically efficient a surface as that possessed by a ground and polished lens. Moreover the reflection loss of the prismatic lens (the angle of light incident being equal) is greater than that of the aspheric lens.

(203) The aspheric condenser, Figure 99I, has a nonspherical surface that tends to reduce spherical aberration.

(204) The light source may be located close enough to the aspheric condenser to pick light through an angle

of almost 100 degrees, as compared with about 60 degrees for the plano-convex combination, and with 78 to 80 degrees for the prismatic type, as estimated by Mazda engineers. Mazda manufacturers claim increases of screen illumination of from 25 to 50 per cent over the prismatic and plano-convex condensers, the greater increase coming with the employment of a short focal length projection lens.

The prismatic condenser, shown in Figure 99H, because of its relatively short source-to-aperture distance is still used with portable projectors, where compactness is essential. (205) Aspheric condensers work best with definite and comparatively short condenser-to-aperture spacing, hence are not efficient with the very

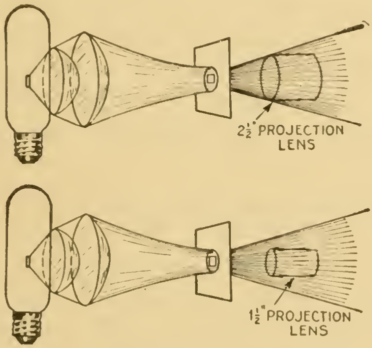


FIGURE 100

long focal length projection lenses employed for still picture projection. For stereopticon projection the plano-convex condenser is compulsory.

The Projection Lens

Since projection lenses are treated more fully elsewhere, they will be discussed here only in their relation to incandescent lamp projection.

(206) As will be observed by examining Fig. 100 in Mazda projection the light beam diverges rapidly between the aperture and the projection lens. If the lens is to intercept most of the beam, the distance of the aperture to the rear element of the lens—which is fixed by

the focal length of lens—and the diameter of the lens are two prime points to be considered.

Repeated tests have demonstrated that the 6.5 inch E.F. No. 2 or "half-size" projection lens, having a greater diameter, will pick up and send forward to the screen approximately twice as much light as the smaller diameter No. 1, quarter size, lens of the same focal length. This difference would be greater were the comparison made between lenses of longer focal length, and smaller if the focal length were shorter, since the change of E.F. automatically affects the working distance, that is the distance from the rear surface of the projection lens to the aperture.

(207) Unfortunately, due to optical limitations, the No. 2 lens is not available in lengths below 4.5 inch E.F.; therefore, below that limit the No. 1 lens must be used. This is not so bad as it appears because the short focal length lens also has a short working distance and consequently it meets the light beam before it has diverged widely.

In any event the projection lens must pick up, as nearly as possible, the entire light beam. If it fails to do so indicates poor and uneven illumination of the screen. Whether or not the beam all enters the lens may be determined roughly by blowing smoke into it.

(208) Projectionists should insist that their Mazda lamp equipments be provided with No. 2 size projection lenses if the E.F. is 4.5 inches or more and an aspheric condenser. Exhibitors and managers should be made to understand that without such lenses there will be a continuous waste of light which means a waste of electric power as well as lessened and uneven screen illumination. It is, in the end, a costly piece of business to force the Mazda to work with a small diameter projection lens of 4.5 or more E.F.

Application Limits

(209) Experience has amply demonstrated the fact that, in general, the 900 watt, 30 ampere Mazda lamp, properly adjusted, efficiently handled, and aided by proper

lenses, etc., can be made to supply satisfactory screen illumination of a very pleasing nature on diffusive screens not exceeding 12 feet in width, or on specular screens not more than 16 feet wide, providing always the screen surface has a good reflection surface and is kept in good condition. This applies to all theatres where the seating capacity is 800 or less on the main floor, and where the viewing distance does not exceed 75 feet.

SOUND EQUIPMENT AND SOUND

The Nature of Sound, page 413

1. Is sound a physical object?
2. How can it be recorded?
3. What is recording?
4. What is the function of theatre sound equipment?
5. What has the nature of sound to do with the operation of theatre equipment?
6. What IS sound?
7. What is the effect of sound upon the human ear?

Some Characteristics of Sound, page 415

8. What is frequency?
9. What is the relation between the pitch of a sound and its frequency?
10. What is volume?
11. What are harmonics?
12. Why are harmonics important?
13. What is resonance?
14. What is the range of sound frequencies audible to the human ear?

Elementary Outline of Acoustics, page 418

15. What is the speed of transmission of sound through air?
16. Is sound transmitted through air in straight lines, as light is?
17. What happens to sound when it reaches the wall of a theatre?
18. What type of material absorbs sound?
19. What is echo?
20. What is reverberation?
21. Name three cures for reverberation.
22. Name four cures for echo.

CHAPTER XIV

SOUND EQUIPMENT AND SOUND

Theatre sound equipment is an apparatus of many parts designed for reproducing recorded sound.

(1) What is recorded sound? Sound cannot be put away in a box and taken out again when wanted; it is not a physical object, but, rather, something that happens to physical objects. It is a condition of highly temporary vibration. This condition cannot be caught and put away, but while it lasts (2) it can be compelled to perform work in the creation of a record. By means of the record so created a new sound may be produced in the future that will exactly resemble the original sound.

(3) The work performed by the original sound is "recording." The creation of a new sound that exactly resembles the original is "reproduction."

(4) Theatre sound equipment is an apparatus of many parts designed to create sounds that will exactly resemble other sounds heard previously in a recording studio.

(5) In order to understand how such equipment operates it is necessary to have some simple knowledge of the nature of sound, and of the work it performs while it is recorded.

Nature of Sound

(6) An ordinary electric buzzer creates sound when its flexible element vibrates, but at no other time. Sound is created when the strings of a violin vibrate, but not when they are motionless. It seems reasonable to suppose that the vibration of a physical object disturbs the particles of air with which it is in contact, causing them also to vibrate. These particles in turn

are in contact with other particles, which, of course, will be similarly disturbed. The area of agitation of the air must spread outward in every direction from the source of vibration, losing energy with increasing distance from that source.

That sound does consist of an agitation of the air, which in turn affects the human ear, can be shown by sealing an electric buzzer in an air-tight glass container and pumping out the air. The sound of the buzzer becomes weaker as the air within the glass becomes thinner, but it is easy to see that the action of the buzzer itself is in no way changed. If the pumping be continued the sound completely disappears, although the buzzer continues to vibrate as strongly as ever.

Surgeons long ago examined the human ear and learned that it contains a membrane of flesh stretched across the opening in such a way that it must vibrate if the air in contact with it does so. (7) From the human point of view, sound is a vibration of the eardrum caused by the periodic increase and decrease of the pressure of air against it. Let us examine this action in somewhat greater detail.

Consider the fraction of a second during which the armature of a buzzer is moving from left to right. All particles of air to the right of the armature will receive a shove and move towards the right until they collide with the next adjoining particles of air in that direction. These next particles are in turn forced ahead for a short distance, until they also lose their energy by similar collisions, in which they push ahead still other particles. At the end of some distance the pushing process reaches some particles of air in contact with the elastic drum of a human ear, forcing the drum to bend inward.

But meanwhile the armature of the buzzer, having completed its motion to the right, has reversed and begun its move leftward, whereupon for a brief instant of time a vacuum exists to its right. Those particles of air nearest the buzzer which a moment ago had been pushed rightward, now rush toward the left to fill that vacuum, leaving a vacuum behind themselves into which air still further to the right must be drawn. The chain of events is now precisely the reverse of that which existed a fraction of a second previously. At the end of the process that particle of air which an instant before had been driven against the eardrum is sucked backward by the sudden appearance of a vacuum behind it, and the eardrum which had just been bent is now sucked outward. An instant more and the buzzer armature moves to the right again and the cycle of events just described is repeated. It may be repeated several hundred times, or several thousand times, in one second, according to the construction of the buzzer.

Pitch of Sound; Frequency of Virbation

If a calling card is held against the teeth of a revolving gear, the edge of the card will act in much the same way as does the vibrator of an electric buzzer. As each tooth strikes against the card its edge is urged forward. When the tooth has passed, the elasticity of the material causes the edge of the cardboard to spring back. As long as the gear continues to revolve the edge of the card will vibrate, just as the armature of the buzzer did.

(8) Now the frequency with which the edge of the cardboard moves can be altered very easily by changing the speed of the gear. Moreover the speed of vibration can be calculated. If the number of teeth in the gear are counted, and its speed of rotation measured, finding out how many times the card moved backward and forward in one second is a matter of simple arithmetic. Thus the frequency of vibration of any sound—the number of cycles of changes of air pressure per second—might be determined by changing the speed of a revolving gear until a similar sound is created by a vibrating card or reed.

If the speed of the gear be increased the pitch of the sound created by the card becomes higher. If the gear slows down, the sound created by the card becomes lower in pitch.

(9) High pitch of sound = high frequency of vibration (many vibrations per second).

Low pitch of sound = low frequency of vibration (few vibrations per second).

Volume of Sound; Strength of Vibration

(10) It seems logical to believe that the intensity or volume of sound corresponds to the intensity or extent of the changes in air pressure. Experiments can easily be made to prove this is true. Slight change in air pressure means weak sound and vice versa.

Fundamental and Harmonic

Let us for a moment return to our vibrating card held against a revolving gear. We have said that the frequency of any sound *might* be determined by means of a toothed wheel and a flexible card. That is true, but the method would not be a very good one. Consider the action of the card edge in somewhat greater detail. When a tooth strikes it the edge is moved forward. After the tooth has passed the natural elasticity of the material causes the edge to spring back; true, but that is not all that happens. The edge of the card does not merely spring back to its original position and remain there rigidly awaiting the next tooth. It springs back a little beyond its original position, and then vibrates back and forth for a brief time before finally coming to rest, all of which occurs between the contact of one gear-tooth and the next. That small secondary vibration while the edge of the card is coming to rest will create a second, weaker sound to accompany the main or fundamental frequency. Because it all takes place between one gear tooth and the next the secondary vibration will be faster—higher in frequency and pitch—than the fundamental vibration.

(11) Such secondary motions exist in nearly all vibrating objects. The secondary sounds accompany most of the sounds we normally hear. One small part of a violin string will vibrate at a much higher pitch

than the string as a whole, thus creating a secondary sound to accompany the fundamental.

Such secondary sounds are commonly called harmonics, while the chief sound or frequency is called the fundamental. Pure sounds, without any harmonics, can be created by means of a tuning fork or by electrical means. "Pure" sounds are commonly recorded on test films or test records, but the sounds of ordinary speech and music are normally very rich in harmonics or "overtones."

Harmonics and Clarity

(12) If a violin and a piano both play the same note, both are creating fundamental vibrations of the same frequency, and the ear could not tell one instrument from the other were it not for the overtones that accompany the fundamental. When two people sing the same song in the same key of music, only the overtones make it possible to distinguish between their voices.

Recording and reproducing equipment must deal faithfully with the harmonics as well as with the fundamental vibrations of sound.

Resonance

(13) If the edge of a moving card vibrates with the frequency of, say, 200 cycles per second, and a violin is held near-by, the G string of the violin may vibrate in resonance. Each time the edge of the card moves toward the string, the string is driven backward by a wave of air pressure; when the vibrating edge moves away from the violin the string is sucked forward by a reduction of air pressure. If the string is so "tuned" that its inherent elasticity permits it to vibrate at 200 cycles per second it will resonate, or keep in step, with the motion of the card. But if the tuning, the elasticity, of the string is not such as to reverse its direction of motion at precisely the same time that the air pressure changes, the motion of the string will get out of step with the changes of air pressure, and resonance will not exist.

Frequency Range of Audibility

(14) The human eardrum is so constructed that its natural elasticity will not interfere with its response to any sound between, roughly, 16 and 16,000 cycles. Sounds outside that range cannot, in general, be heard by the human ear. The exact range differs rather widely with different individuals; it also changes with increasing age. The ear is most sensitive to sounds around 1,000 cycles. The very high-pitched and very low-pitched sounds require more volume to make them audible to us.

Transmission of Sound

Sounds can be heard under water. An ear placed against a wall will hear vibrations in that wall that are not audible in the neighboring air. Very many substances are capable of vibrating at the audible frequencies. In other words, they are capable of transmitting sound. But in practical theatre work we are concerned chiefly with air as a medium of transmission.

(15) All sound vibrations, regardless of their frequency, are transmitted through air at a rate of about 1,000 feet per second. The speed varies slightly with temperature and moisture. It is generally somewhat more than 1,000 feet per second (closer to 1,100 feet) but the number first given will be sufficiently accurate for all practical acoustic work the projectionist is ever likely to encounter, and it is very easy to remember.

(16) Some frequencies of sound seem to radiate from their source in straight lines much as light does, and constitute beams of frequencies that can only be heard when one stands directly in the line of the loud speaker. But a very large number of frequencies wrap themselves around obstructions much as a ripple in water will wrap itself around a rock. It is not difficult to convey understandable sound to every seat of a theatre, but to provide every seat with its full share of all frequencies, including those that tend to travel in straight beams like light, is sometimes not at all easy.

It often calls for much prolonged and patient work in pointing and repointing the speakers.

Reflection of Sound

(17) When an air wave strikes against the human ear-drum it bends the drum inward, but if that organ were rigid and could not bend, the wave would have to rebound from it, and thus begin a wave of reflected sound. This happens when sound strikes the wall of a theatre unless that wall has been treated with "sound-absorbing" material. Such material may consist of thick drapes, of special plaster, or of anything (18) that contains a great number of very narrow air channels into which the vibration penetrates and is lost by reason of the friction between the particles of air and the extremely confined passages in which they must move.

The sound-absorbing power of acoustic drapes or plaster is not, however, the same at all frequencies. Consequently great care is required in choosing absorptive material for "acoustic treatment" of an auditorium, and such treatment is, in general, best left to acoustic experts.

Sound is reflected from a hard, smooth wall in the same way that light is reflected from a mirror—at the equal but opposite angle. But except for those frequencies that tend to travel as beams the reflected sound, like the original, will spread and wrap itself around obstructions and corners.

(19) A mirror presents a smooth, very close-grained surface to the minute waves of light, and therefore reflects a precise image. White plaster, although it reflects light, still is rough in comparison to the size of the light-waves and diffuses them so greatly in the process of reflection that no image is recognizable. The waves of sound are enormously large in comparison with the waves of light. A smooth plaster wall may reflect them with no appreciable distortion. The result is that the reflected sound is heard a fraction of a second after the original sound. This is echo.

The reflecting surface responsible for echo in a theatre can sometimes be located by timing the interval between the direct and the reflected sound, remembering that both travel at approximately 1,000 feet per second.

REVERBERATION

(20) Just as a plaster wall presents a rough surface to the waves of light, and distorts them in reflecting them, so a wall broken up by doors, columns or other large irregularities will distort the sound it reflects until it is no longer recognizable as an image of the original sound. Music or words cannot be distinguished. This form of reflected sound is called reverberation. Moreover, repeated reflections from even the smoothest walls and ceilings will also cause reverberation. It is a very common and very troublesome fault in theatres. Echo, as we can now see, is merely one type of reverberation—that type in which the sound is not distorted by reflection.

(21) The easiest remedy for reverberation is to use the lowest possible volume. Most theatre sound is much too loud. (See Page 639.) The next easiest is to point the speakers away from the reflecting surface and toward absorbing surfaces—such as the audience itself. The most troublesome and expensive remedy, but the surest, is to install drapes or acoustic plaster over the reflecting surface. Re-plastering should always be directed by an acoustic consultant; it is too expensive an operation to experiment with.

(22) Since echo is merely a special form of reverberation (that form in which the reflected sound is not distorted) it is treated by any of the methods just mentioned. In addition, it can be attacked by breaking up the reflecting surface through use of coffering (artificial recesses in the wall or ceiling). This last will cause distortion of the reflected sound and convert the echo into reverberation, which is the lesser of the two evils.

RECORDING AND REPRODUCTION

The Nature of Recording, page 422

1. What is the relation between the action of human eardrum and the action of one important portion of recording equipment?
2. Why is the old-fashioned, familiar *mechanical* phonograph worth consideration in a study of electrical recording and reproduction of sound?

Early Methods of Recording, page 422

3. Describe the recording action of the old-fashioned phonograph.
4. What two types of record did it make?
5. Describe its action in reproduction.

Problems of Recording, page 424

6. Why is turn-table speed very important?
7. What is flutter?
8. What is hunting?

Modern Methods of Recording, page 424

9. Can a record to create sound be made without the help of any previously existing sound?
10. Why does theatre work require *electrical* recording and reproduction?
11. Outline the method of recording and reproducing sound electrically.
12. What two types of film sound-track are created by electrical recording on motion picture film? Identify them in Figures 101 and 102.

CHAPTER XV

RECORDING AND REPRODUCTION

From what has been said it should be clear that the recording and reproduction of sound, once the fundamental nature of sound is understood, does not present any remarkable difficulties. (1) It has been explained that "from the human point of view sound is a vibration of the eardrum caused by the periodic increase and decrease of the pressure of air against it." Substitute a properly designed mechanical eardrum (a suitable diaphragm of metal instead of flesh) and the vibrations that constitute sound may readily be scratched in moving wax, photographed on a moving film, used to magnetize sections of a moving wire, or in fact recorded in a great many ways. Long after the sound has performed its work and died away the record can be used to operate some form of small air-pump, as, for example, a head telephone or a loud speaker, and thus re-create the identical sequence of changes in air pressure at another time and place.

How simple it really is to accomplish this may be made more clear by considering the old-fashioned mechanical phonograph. (2) In fact it will be worth our while to give that obsolete instrument some brief consideration. When a few simple mechanical details have been gone over and are out of our way, we can proceed to study modern, electrical recording and reproduction with disc or film, and then only the electrical principles involved with need detailed attention.

The Mechanical Phonograph

In this contrivance the essential recording element is a small disc of metal constituting an artificial eardrum. This, much like the drum of the human ear, is so mounted that it is free to vibrate in resonance with changes of air pressure carried to it by a horn or megaphone. Consequently, when sound (air) vibrations impinge upon this disc it will bend inward and bulge outward in resonance with the frequency of the sound, precisely as does the human eardrum, and for precisely the same reasons.

(3) A metal needle or stylus is rigidly attached to the center of the disc, so that every vibration the disc undergoes must be duplicated by the point of the needle. The needle may be mounted above a turn-table and on this turn-table may be placed a very thick, blank phonograph record made of soft wax. The turn-table is made to rotate at some fixed, unvarying speed, the needle is lowered until it cuts into the moving wax. Since the needle, together with its disc or diaphragm, is mounted upon a worm gear which moves it slightly sidewise at each rotation of the wax, it cuts a spiral groove, as may be seen on any phonograph record.

Now whenever sound waves reach the little metal diaphragm the point of the stylus must vibrate in resonance with them. In most recording this vibration causes the groove cut by the stylus to waver slightly from side to side. (4) Some records are so made that the vibrating point cuts deeper or shallower, creating what is known as "vertical cut" or "hill and dale" recording. The fundamental principle of "hill and dale" is, incidentally, not new. It is older than the other, or lateral, cut, but has recently been improved to give strikingly superior results. Whichever method is used the wax is engraved with a series of physical markings that corresponds exactly to the sequence of changes in air pressure. The slight variations in the groove cut by the stylus are the work the sound performed while it lasted, and by means of them a duplicate of that sound can be created at any time after the record has been made permanent. This is done by dusting the wax with carbon powder and electroplating metal upon it.

Assume that the wax has been so treated, and the resultant metal perhaps used to manufacture many similar records through a stamping process. (5) Then the same equipment that made the record will serve to play it back. The permanent record is placed under the stylus, the turn-table is rotated again at the same speed as before, and the needle is allowed to follow the groove it made while it was acting as a recorder. When the point of the needle encounters the small variations cut in the groove it must vibrate; its vibrations will be communicated to the diaphragm; the diaphragm must vibrate and impart its vibrations to the air around it, and a reproduction of the original sound will be heard.

That, in principle, is all there is to the mechanical phonograph, as well as all there is, in principle, to the purely mechanical portions of electrical recording, whether on film or disc.

There are some details that need further attention. One is the speed of rotation of the turn-table. (6) The reproducing speed must be identical with the recording speed. Suppose that at a certain low note the needle cuts a hundred variations in the groove in a second's time. Then, during playback, the needle must encounter a hundred deflections of its course through the groove during the same interval of one second. Otherwise the note played back would be either higher or lower in pitch than the original note.

(7) Moreover, the speed of rotation, during recording and playback both, must be constant, otherwise the pitch of the sound will change, or flutter. (8) A slow flutter, slow change in turn-table speed, is called "hunting." A very slight change of speed makes a very great difference, especially with respect to the higher frequencies of sound.

(9) A record, whether disc or film, need not necessarily be a record of actual sound. Test records and films are sometimes made by purely electrical means, which cause the needle or the light-shutter to vibrate at any desired frequency, without the existence of sound in the air at all.

(10) The recording diaphragm must be delicate enough to catch the faintest vibrations of sound, includ-

NEED FOR ELECTRICAL PHONOGRAPHS

ing the very weak but audible harmonics, yet sturdy enough to engrave the loudest sounds upon the wax without any distortion. That is an impossible combination of requirements. The mechanical phonograph never was able to record the faint higher harmonics, nor faithfully to engrave very low, low sound. The play-back diaphragm had to be sturdy enough to move large volumes of air with the energy necessary to produce loud, low-pitched sound, but sufficiently delicate to respond to the faintest deflection of its needle when reproducing weak, high-pitched overtones. Another impossible combination. There are other draw-backs to the older method, but these two are enough to show the essential necessity for electrical equipment.

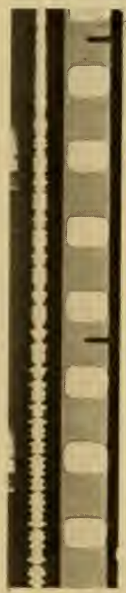


FIG. 101. One type of constant density, variable amplitude sound track.

(11) In electrical recording an extremely sensitive diaphragm catches the faintest sounds and converts them into amazingly weak electric currents. The weakness of those currents is no handicap, since they can be amplified. After undergoing amplification they operate either a stylus that cuts wax or a shutter that varies light admitted to a moving film. In reproduction a sensitive "pick-up," or an even more sensitive photo-electric cell, again create currents of unimaginably minute strength, which are amplified until they are able to drive the comparatively heavy diaphragm of a theatre loudspeaker.

(12) The two common types of recording shutters produce two different forms of film record, or "sound track." One operates by varying the area of film upon which light is permitted to fall. This is known as "variable area, constant density" recording. The other varies the intensity of the light from zero to maximum, but the width of the illuminated area does not change.

Fig. 102.—Constant amplitude, variable density sound track, highly magnified.

This is known as "constant area, variable density" recording. Both, as will be explained later on, can be used on the same projector without change or adjustment.

Fig. 101 is a "noiseless recording." The clear area of the track varies in width and never admits more light to the photocell than just enough to account for the sound volume needed at that moment. Hence photocell hiss is always weaker than the sound at any volume and is never heard.

Fig. 102 is also noiseless recording. The degree of shading of both light and dark areas is adjusted to limit the light reaching the photocell as the width of the clear area is adjusted in Fig. 101 for the same purpose.

But we cannot well consider the details of electrical methods of sound reproduction without a short detour into the nature of electricity similar to, but rather longer than, the detour we have already made into the nature of sound.

ELEMENTS OF ELECTRICITY

Nature of Electricity, page 428

1. Why was it necessary recently to substitute the idea that current flows from negative to positive for the older idea that current moves from positive to negative?
2. Why is electrical theory helpful in practical work?
3. Where do atoms exist?
4. Of what are they composed?
5. Do we work with positive and negative electricity, or with one kind only?
6. Name three kinds of apparatus in which negatrons are detached from their atoms and made available in their free state.

The Meaning of Some Common Electrical Terms, page 430

7. What is an electric current?
8. What is a coulomb?
9. What is an ampere?
10. What is a negative charge?
11. What is a positive charge?

The Nature of an Electrical Current, page 431

12. Why will negatrons move away from each other, if they are in a medium that permits them to move?
13. What is the effect of negatrons in motion?
14. What is an electro-motive force?
15. What is a conductor?
16. What is an insulator?
17. What is resistance?
18. What effect has flow of current upon the conductor carrying it?

CHAPTER XVI

ELEMENTS OF ELECTRICITY

There once was a theory that electric current moved from positive to negative. Today it is agreed that that theory was exactly 100 per cent wrong; that current actually moves from negative to positive. But the old idea, in spite of the fact that it was wrong, was useful, and still is. It helped create electric lights, dynamos, telephones, street cars, and a good many other very valuable electric appliances, and they worked; and when they stopped working men could fix them in accordance with the theory that current moved from positive to negative. It is a useful theory today. Any number of electricians and engineers, thoroughly convinced that current flow is from negative to positive, nevertheless run down trouble in a circuit by starting at the positive end, merely as a matter of habit and because they find it handier to do so.

Obviously, then, a theory doesn't have to be right to be useful. And for practical work, as apart from pure science, a theory that is useful, and can be applied successfully to practical apparatus, is all that is necessary. In many places in this book current is spoken of as moving from positive to negative, and any circuit spoken of in that way is one in which the projectionist will very probably find it handier—more convenient—to think about the action in accordance with the older idea. In the case of most electrical circuits, either theory will do.

(1) But the idea that current moves from positive to negative, while convenient in the case of ordinary circuits, won't work at all in the case of vacuum tube circuits. With such apparatus it is absolutely necessary to think of current as moving from negative to positive,

otherwise the functioning of the equipment remains a mystery. But both theories explain the action of all ordinary circuits equally well, and this is one of the many reasons for the modern assurance that the old theory is wrong and the new one correct.

The explanations of electrical actions we will outline are the most recent, and seemingly well founded. They may or may not be true, but they are unquestionably useful. (2) The man who remembers them doesn't have to remember an immense accumulation of details and facts. Very many of the details he needs in practical work will be found to be small parts of one general theory, which in itself is extremely simple.

Electrons and Atoms

Everything in this world is now thought to be composed of electricity and something else. What the "something else" is remains to be discovered. From time to time newspapers tell us that another scientist has tried to break open an atom and find out. Whatever it is it is something 1,800 times as heavy as electricity, and it need not bother us any further.

(3) Every physical thing we touch is made up of atoms, (4) and atoms are built of positive and negative electricity, plus this other thing that is 1,800 times as heavy. A hydrogen atom is very simple. It has a core or nucleus in which (according to the latest theory at the time this is written) there is the heavy unknown entity and one positive electron, or "positron." Outside the core, circling around it so fast that it can't be drawn into the core by the attraction of the positron, is one particle of negative electricity, the negative electron, or "negatron."

All other atoms are more complicated. Oxygen, iron, copper and so on have many positrons and negatrons in their cores, or centers, but always more positrons than negatrons. To balance the extra positrons in their centers they need anywhere from two to ninety negatrons outside, circling around just as the one negatron circles around the hydrogen core. These outer negatrons are arranged in many layers like the layers of an onion, one inside the other.

In ordinary electrical work, nothing can ever be taken from an atom except one of its outermost negatrons. The positron, or positive electricity, has only been separated in a very few laboratories.

(5) All the electricity we know and work with is negative electricity.

The details of the structure of atoms, even in this extremely sketchy description, are of no practical importance to the projectionist, who need not bother to remember them, except for the sake of interest or curiosity. All he need remember is that he can't work with, or obtain, anything except negative electricity. All his electrons are negative—negatrons. That one point should be remembered. It will explain almost everything else.

(6) Negatrons are detached from atoms in photoelectric cells, in vacuum tubes and in any ordinary battery. The means used in each case will be explained in detail further along.

(7) Negatrons moving through a conducting wire constitute what we call an electric current. They have plenty of room to move in a solid copper wire because the wire itself is composed of atoms of copper, and an atom of copper is a very small core surrounded by clouds of negatrons, somewhat as you might imagine an apple hung in the air, and surrounded by clouds of buzzing flies. But all negatrons are negative and like charges repel. The outer negatrons of one atom have a repellant effect upon the outer negatrons of its neighbors. There is space between the atoms, which after all are mostly clouds of negatrons. Copper wire seems solid to us, even under a microscope. But a negatron which is not part of any atom and is moving through the wire as part of a current finds the interior of that wire almost entirely open space.

Negatrons have been weighed and measured. When 6,281,000,000,000,000,000 (six quintillion, 281 quadrillion) of them pass through the ammeter in one second's time, they constitute an ampere of current. That number of them will light a hundred-watt lamp for one second. (8) They constitute one coulomb of current. (9) And the flow of one coulomb in one second constitutes one ampere; one coulomb in two seconds being one-half ampere, and so on.

Negations, Electric Charges and Currents

Negatrons exist everywhere on earth, apart from any atom or any positrons. (10) Wherever an exceptionally large concentration of them exists the place or object carrying them possesses a negative charge. (11) Wherever there are less than the normal number of negatrons, that place or object has a positive charge.

(12) Since all negatrons are negative, and like charges repel, negatrons will move away from each other if they can, by force of their mutual repulsion. They will spread out until their concentration, which is the negative charge, has disappeared. And since opposite charges attract, they will by preference move in the direction of a positive charge—that is, toward a point where there exists less than the normal concentration of negatrons. One might almost say they don't like each other—they will always move away from a crowd of their own kind, if they can, to a place where fewer of their kind exist.

(13) Negatrons in motion constitute a current. (14) Their mutual repulsion, the attraction of a positive charge, or any other force that impels them to move is called an electro-motive force.

Conductors and Insulators

We are not concerned here with liquids but only with solid conductors. (15) Those solid substances through which a relatively small electro-motive force will move large numbers of negatrons are said to conduct current readily. Such substances are called "conductors." (16) Others are called insulators. Some materials (carbon is an example) do not fall clearly within either class, but may be regarded either as poor conductors or imperfect insulators. There are no perfect insulators. Dry sulphur at normal temperatures is very nearly perfect. A block of sulphur an inch square, under an electro-motive force of one volt, will allow only a few thousand negatrons to pass through it in one second. It therefore constitutes an admirable insulator. A block of copper an inch square, with the same electro-motive force applied, will pass many millions times millions times millions of negatrons in one second's time.

The amount of hindrance any conductor offers to the passage of negatrons is called the (17) resistance of the conductor. It is measured, in ohms, by comparison with a standard resistor made of mercury.

Nature of Conduction

Why some substances hinder the flow of negatrons more than others is still very much a mystery. But it is noteworthy that all the good conductors have only one negatron in the outermost layer of their atoms. It may be that those substances that have many negatrons in the outside layer of their atoms repel the free negatrons that constitute an electric current by reason of the mutual repulsion of like charges.

(18) Conductors are heated by the passage of current. The effect of a negative charge moving through the balanced positives and negatives of a system of atoms apparently sets the atoms into vibration at a frequency which constitutes heat. When the resistance is great the substance of a conductor undergoes internal vibration at a still higher frequency and in consequence it may emit visible light.

BEHAVIOR OF A SIMPLE CURRENT

Factors Controlling the Flow of Current, page 434

1. What is potential?
2. What is a difference of potential?
3. What is the electrical effect of a difference of potential?
4. How is potential difference measured?

Ohm's Law, page 434

5. What two factors govern the amperage, or current flowing, in any circuit?
6. What is an ohm?
7. Is an ampere a definite quantity?
8. What is a volt?
9. What is Ohm's Law?
10. Why is it true?

CHAPTER XVII

BEHAVIOR OF A SIMPLE CURRENT

(1) Whenever any point, area or object possesses a concentration of negatrons greater or less than normal, that place or object is "charged," either positively or negatively. The strength of any charge with respect to the normal charge of earth is called its "potential." Thus, if a glass rod is rubbed with silk, negatrons are taken from the glass and left on the silk. Just why or how this occurs no one knows, but it is certain that the silk is found to be negatively charged, and the glass charged to a positive potential, meaning, as before explained, that there is a lack of negatrons in the glass and a surplus of them in the silk.

(2) When two places or objects are differently charged, a difference of potential exists between them. One may be positive and the other negative; or both may be negative, but one more so than the other. Or both positive but one more strongly than the other. (3) Any difference of potential constitutes an electromotive force. If a conducting path exists negatrons will flow from the area of greatest concentration to the area of least concentration until the difference has been equalized.

The number of negatrons flowing per second constitutes the amperage.

(4) The difference of potential is measured in volts.

(5) Obviously the amperage flowing in any circuit will depend both upon the potential difference which causes the current to flow and upon the resistance of the conductor. The greater the potential difference, or the less the resistance, the greater the number of negatrons will pass through the meter in one second of time in the

effort to equalize that potential difference. The effect has often been compared to that of water being pumped through a pipe; a very helpful comparison by the way. The effect of steam under pressure perhaps gives an even closer mental picture, because negatrons are very definitely under pressure—the pressure of their own repulsion of each other. But since their motion, in their attempt to spread out as far from each other as possible, must take place against the resistance of the conducting medium, an increase in resistance evidently decreases the current flow, just as the increase in potential difference causes the current flow to become greater.

Ohm's Law

Potential difference is measured in volts, current in amperes and resistance in ohms. An ohm is a very definite thing. (6) It is the resistance offered by a certain standard resistor. (7) An ampere is likewise definite since it consists of a certain very large number of negatrons passing a given point in a wire in one second's time.*

(8) But for the sake of convenience in arithmetic one volt is that potential difference which will cause one ampere to flow through a resistance of one ohm.

Therefore, if the current is one ampere and the resistance of the circuit one ohm, what is the voltage? The answer has just been given: it is one volt. And if the resistance is one ohm and the current is ten amperes the potential difference that is causing the current to flow obviously must be ten volts. Then if the current is ten amperes and the resistance is six ohms, the potential difference must be sixty volts. Consequently:

(9) volts = amperes × ohms.

This is usually written:

E (volts) = I (amperes) × R (Resistance)

In which case the reader who remembers his arith-

*More accurately, according to the definition agreed upon before negatrons were known, an ampere is the current capable of performing, under accurately controlled conditions, a certain measured amount of electro-plating in one second of time.

metic will see instantly that the following must also be true:

$$I = E \div R$$

and:

$$R = E \div I$$

The reader who may have forgotten so much of his arithmetic that he doesn't see why the two other forms of Ohm's Law must of necessity follow or result from the first, may ask himself these questions:

If 60 volts force 10 amperes through 6 ohms, is it not obvious that 6 equals 60 divided by 10, and therefore that the resistance must equal the voltage divided by the current? In the same way, is it not true that the current (10 amperes) must equal the voltage divided by the resistance (60 divided by 6)?

The result arrived at will be the same with any other set of numbers. Try it. Write the first form of Ohm's Law, $E = I \times R$. Chose any numbers at all for I and for R. Multiply them together to find the E of that particular circuit, and it will be found that I always equals E over R and that R always equals E over I. No matter what numbers are chosen, the result will always balance.

(10) If one volt is the force necessary to drive one ampere through one ohm, then all three forms of Ohm's Law must be true by arithmetical necessity.

It is by "fooling" Ohm's Law that an amplifying tube amplifies sound currents. How this is done will become plain a little further on when certain other electrical fundamentals have been considered.

Simple ohm's law, easily remembered

$$\frac{E}{I \times R}$$

just cover the desired one, and work out

SERIES AND PARALLEL CIRCUITS

Two Simple Circuits, page 438

1. What is a parallel circuit?
2. What is a series circuit?

Calculation of Voltage Drop, page 439

3. If two 110-volt lamps are connected in series and supplied by a 110-volt line, what will be the voltage drop across each lamp?
4. What is the voltage drop across a four-ohm resistor carrying ½ ampere?
5. What is the voltage drop across a six-ohm resistor carrying ½ ampere?
6. What is the voltage drop across a two-ohm resistor carrying ½ ampere?
7. What is the total voltage drop across all the resistance in a 6-volt series circuit?
8. Is the phenomenon of voltage drop useful in studying the wiring of amplifiers?

CHAPTER XVIII

SERIES AND PARALLEL CIRCUITS

Figure 103 is a diagrammatic representation of a typical lighting circuit in which two lamps are connected across the line. Arrowheads indicate connection to the source of power, which is presumed to be a normal 110-volt generator.

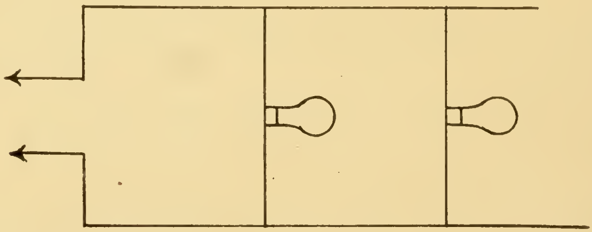


FIG. 103.—Lamps connected in parallel (shunt or multiple).

Under these conditions the voltage drop across each lamp is the full voltage of the line. If these are 100-watt lamps that voltage will compel approximately 9/10 of an ampere to flow through the resistance of each filament. The 110-volt potential difference existing between one of the circuit wires and the other is maintained by action of the generator notwithstanding the flow of current through the lamps.

(1) Figure 103 represents a typical parallel circuit, meaning that the items (in this case lamps) are connected in parallel (multiple, shunt) to each other.

Let us compare figures 103 and 104, assuming that the line pressure in each case is 110 volts. (2) Figure 104 is a series connection, and it is readily understood that no current can flow in either lamp filament that does not flow through the other filament also.

Under this condition the current must overcome the combined resistance of both filaments in completing its course from highest to lowest potential. This being true, it follows by Ohm's Law that, since the resistance of the path has been doubled without altering the voltage, each lamp will receive only half of the current it would if it were working alone on 110 volts as in Figure 103. The connection shown in Figure 104 is therefore obviously unsuitable for 110-volt lamps, being shown here merely to illustrate the principle under discussion;

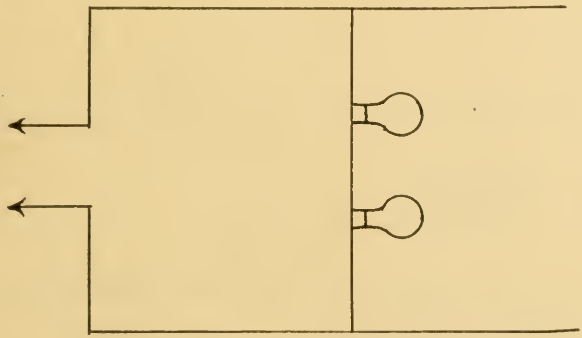


FIG. 104.—Lamps connected in series.

but it would be entirely suitable for 110-volt lamps supplied by a 220-volt line.

(3) In Figure 104 the voltage remains unaltered while the resistance has been doubled, which, in effect, means that each lamp receives only half its alloted amperage, while the voltage drop across each lamp is 55 instead of 110.

Let us now examine Figure 105. Before the current completes its course through that circuit, it will have encountered and overcome a total of 12 ohms resistance, disregarding the slight resistance offered by the connecting wires themselves. We note that the potential difference (voltage) built up and maintained by the battery is six volts.

Query: What amperage will flow?

This is answered by Ohm's Law, which says that voltage divided by resistance in ohms ($E \div R$) equals amperage (I), therefore 6 volts divided by 12 amperes will be exactly one-half an ampere. This current must flow through all the resistors, since all are in series.

Now let us examine the voltage drop across each resistor. In other words, what voltage is required to

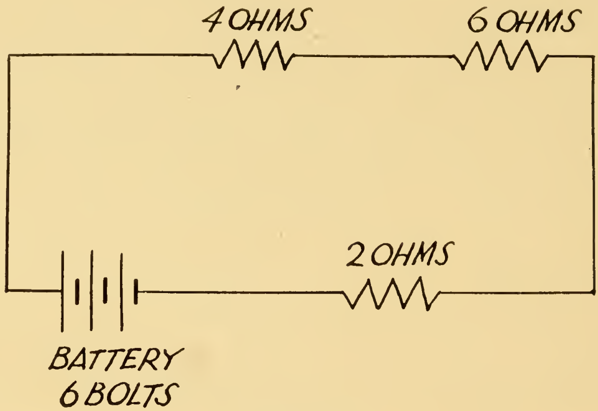


FIGURE 105

force one-half ampere through each separate resistor in Figure 105?

(4) To force the half ampere through the resistance of four ohms requires (I × R) the consumption of 0.5 × 4 = 2 volts. In other words the flow of 0.5 of an ampere through 4 ohms necessarily means a 2-volt potential difference, or as it is usually stated "voltage drop," between the two ends of the resistor.

A more accurate way of stating the same fact is to say that a two-volt potential difference must exist across the terminals of a four-ohm resistor in order to compel 0.5 ampere to flow through it. (5) The drop across the 6-ohm resistor, calculated similarly, is found to be three volts, (6) and that across the 2-ohm resistor one volt, therefore we have a (7) total drop of 2 + 3 + 1 = 6 volts, which accounts for the entire 6-volt line pressure.

We have disregarded the wire resistance, which, unless the line be a long one, would be negligible. It is nevertheless present and reduces the 0.5 ampere current we have assumed here to something very slightly less than 0.5 ampere.

(8) It will later be found that a thorough understanding of drop in voltage due to resistance is of considerable importance in considering the internal wiring of amplifiers, therefore we have tried to make the action very plain, even at some risk of boring the reader.

HOW NEGATRONS ARE OBTAINED FROM BATTERIES

Electro-chemical Fundamentals, page 444

1. Name one source of negative electrons, or negatrons.
2. Where do the negatrons drawn from a dry cell originate?
3. What is an ion?
4. What is a molecule?

The "Dry-battery," page 445

5. What action, in a dry cell, detaches negatrons from their atoms?
6. Where are they to be found after they have been so detached?
7. What force causes them to move through an external circuit?

The Storage Battery, page 446

8. When a storage battery is discharging, what happens at the negative plate?
9. What happens at the positive plate?
10. Where, in a storage battery, does lead sulphate form?
11. Where does the sulphate in the lead sulphate come from?
12. What is the effect of discharge upon the solution of a storage cell?
13. With what instrument can that effect be measured?
14. Will that instrument indicate the state of charge of the cell? Why?
15. What action in the cell causes a storage battery to lose voltage in the course of discharging?
16. What does re-charging the cell do?
17. Name two causes of deterioration of a storage battery.
18. Why must a storage cell be over-charged occasionally?

CARE OF STORAGE BATTERY, PAGE 447

19. What precaution is necessary in charging a storage battery?
20. What is "gassing"?
21. Name two kinds of injury caused by excessive gassing.
22. Name three necessary precautions in the care of storage batteries.
23. Does the battery acid evaporate? Is it lost in any other way?
24. Why are battery terminals kept greased? prevent corrosion.
25. What damage is done by unclean battery tops?
26. What kind of water is used to re-fill storage batteries? Why?

CHAPTER XIX

HOW NEGATRONS ARE OBTAINED FROM BATTERIES

(1) One of the simplest and most familiar sources of negative electrons, or negatrons, is the common zinc-carbon "dry" battery that is used in flashlights and for ringing door-bells, and in sound systems as the "B" battery and "C" battery. (2) The negatrons drawn from any "dry" cell originate in the atoms of its materials, and are removed from those atoms by chemical action.

We saw a few pages back that every physical substance is composed of atoms, and that all atoms contain negatrons, the difference between one atom and another being partly in the number of negatrons each contains and the manner in which they are arranged.

Ions

(3) We also saw that every atom contains a positron or positrons, which, however, can only be removed from the atom by very modern laboratories. In every atom the positive and negative elements are roughly balanced, but the balance is not always perfect. Negatrons can be removed from atoms, leaving them more positive than they were before; or atoms can take on an additional negatron or negatrons, becoming more negative than they were before. Thus an atom may be either positively or negatively charged, and in either condition is called an "ion." Ions generally represent a temporary condition, since an atom that has become charged, or ionized, through gaining or losing electrons, tends to return to its normal or "atomic" condition.

Molecules

(4) Two atoms or two ions which are electrically

unbalanced may be permanently united into a single unit by virtue of the interaction of their charges, in which case continued attraction holds them together. Such a union of atoms is called a molecule. Most substances consist of atoms that have united to form molecules. There are very few exceptions. Water, as everyone knows, consists of molecules made up of two atoms of hydrogen and one of oxygen. Hydrogen peroxide contains two hydrogens and two oxygens, but this arrangement is not electrically stable. The extra oxygen tends to break away at the least provocation. Oxygen in the air that we breathe does not consist of single atoms, but of molecules, each of which contains two oxygen atoms.

The Dry Cell

(5) The source of the negatrons obtained from a dry cell is the zinc metal that forms the container. The interior of the cell is filled with a semi-wet paste that contains, among other things, molecules of ammonium chloride. The action of the paste upon the zinc of the container is such that some of the zinc atoms are positively ionized, whereupon they dissolve into the paste. The negatrons they lost when they became ions remain behind, (6) constituting a charge upon the container.

Just as there is a limit to the amount of sugar that can be dissolved in a cup of coffe, there is a limit to the amount of zinc that can be dissolved in the paste of a dry cell. In the center of the cell, however, there is a carbon rod, which is in intimate contact with the same paste. When the carbon rod is connected with the zinc can by means of an external wire, forming a closed circuit, the process of dissolving zinc becomes continuous, and a steady supply of negatrons is released at the zinc or negative terminal of the cell.

This happens because the negatrons already accumulated on the zinc are driven, (7) by force of their mutual repulsion (which is voltage) to move through the connecting wire to the carbon rod. There they enter into the solution and break up the ammonium chloride molecule by upsetting its electrical balance. A new molecule is formed, in which the zinc that had been dissolved from the can is included. The paste then becomes able to dissolve more zinc, leaving more negatrons behind on the container, and the process can continue as long as the can and the carbon rod are connected by a conductor and the cell is still "alive." But after it has continued for a period of time the battery "dies," partly because the active material of the paste has been exhausted and partly through a variety of chemical changes, the small details of which are not of great interest to projectionists.

The Lead Storage Battery

The chemistry involved in the action of storage batteries is more complex than that of dry cells, and will be dealt with only in brief outline. The full story of that battery, as well as of the dry-cell, can be found in any modern text-book of chemistry. (8) (A) Sulphate ions in the sulphuric acid which storage cells contain unite with the lead of the negative plate to form molecules of lead sulphate. (B) Each atom of lead that enters into this combination loses two negatrons, which move through the external wire to the positive plate. (9) (C) Here their presence breaks up molecules of lead dioxide, each of which consists of one atom of lead and two atoms of oxygen. Through an intermediate chemical formation, that need not be traced in detail, the presence of these negatrons results in the formation of lead sulphate on the other plate also, as well as the release of oxygen. (10) (D) The sulphate that goes to make up the lead sulphate formed on both plates (11) comes from the sulphuric acid, which is only another name for hydrogen sulphate. Divorced by its sulphate partner, the hydrogen unites with the oxgen released at the positive plate, forming water. (12) Therefore when the battery has been used for a while its solution contains less sulphuric acid, and more water. (13) This change can be measured with a hydrometer. (14) In consequence that simple instrument tells how far the cell is exhausted, and whether it stands in need of recharging.

(15) (E) The lead cell of storage batteries must be re-charged long before its sulphuric acid is all used up, because the lead sulphate that forms on both plates ultimately becomes thick enough to insulate the solution from the active material, therefore the chemical action slows up and the voltage of the cell declines.

(16) (F) Re-charging of this cell involves the introduction of new negatrons from an external source, which by their presence upset the electro-chemical balances created during the state of discharge and restore the original condition. The amount of sulphuric acid in the solution is increased during charge as the sulphate leaves the plates, and the oxygen divorces the hydrogen to return to its original partnership. The hydrometer measures this change and tells when the battery has been completely re-charged.

(17) Storage batteries deteriorate through several causes. In commercial batteries some of the active material drops from the plates during each cycle of charge and discharge, piling up at the bottom of the cell. Thus the plates lose some of their power. Eventually the heap of material at the bottom may grow high enough to short-circuit them. Again, the lead sulphate that forms during discharge is seldom completely disintegrated during charging. A surplus usually remains that must be removed by occasional over-charging. (18) If this is not done the layer continues to accumulate until it has become so thick that no ordinary charging will remove it and the battery must have special treatment or be thrown away. There are other causes of battery deterioration but these two are of prime importance. Others are described below.

Care of Storage Batteries

(19) While it is necessary, as has just been explained, to overcharge a lead battery occasionally, it is much more important not to overcharge it often or unintentionally.

(20) All charging boils out some of the water of the solution—a process called "gassing." (21) Gassing

loosens active material from the plates and causes it to fall to the bottom of the container as sediment, thus shortening the life of the battery. Gassing, and therefore charging, should consequently be limited to just so much as is necessary to prevent accumulation of excess lead sulphate, and no more. Excessive gassing may also cause some of the sediment to boil up from the bottom and deposit on the plates or the porous separators between the plates, thereby forming an internal conducting path that partly short-circuits the cell. (22) Manufacturers' specifications as to charging should be followed carefully and intelligently. Otherwise the cell needs only external cleanliness, and periodic replacement of the water that has evaporated.

(23) The acid does not evaporate but some spray of acid will be blown out of the ventilation openings by gassing during charge. Generally, the amount of acid lost in this way is so small that new acid will never be needed during the life of the battery. Sulphuric acid is not added to batteries. If it is needed the cell is emptied and a new solution of acid and water poured in; which is not, in general, a job for the projectionist, but for a battery expert. (24) The acid lost through gassing, though not enough to make much difference inside the cell, becomes, however, a very serious matter when it collects on the outer surface. It corrodes the terminals and the connecting wires to an extent that may result in imperfect contact and therefore in noisy sound.

Trouble from this source is prevented by keeping the terminals of the battery carefully greased. This is a very important precaution.

(25) Spray of acid collecting upon the top of the battery forms a conducting path of high and often of variable resistance. Noisy sound may be caused by unclean battery tops. Acid spray should be carefully washed off with excess of pure water. Ammonia will neutralize the acid and a weak solution of it is sometimes used for washing the tops of storage batteries.

(26) The only safe water to use in a storage battery, to make up for evaporation, is distilled water. Hydrant

water in some communities will do no harm at all, but in others ordinary harmless drinking water contains metallic impurities that will damage the battery seriously. Distilled water is too cheap to justify taking chances with an expensive battery installation.

NEGATRONS FROM PHOTO-ELECTRIC ELEMENTS

Temperature-controlled Emission, page 451

1. Do metals always emit negatrons?
2. What happens to the emission if the metal be heated?
3. Is emission useful when it takes place in air?
4. What is a "space charge"?
5. What is the source of the negatrons emitted by an electrically-heated wire?
6. Describe the action of "heater filament."
7. Describe the action of a "cold emitter" tube.

Photo-electric Emission, page 453

8. What is a "photo-electric" metal?
9. Name two metals used in photo-electric cells.
10. Explain the increased emission from metals under the influence of heat.
11. Can the action of light in causing increased emission be explained?

CHAPTER XX

NEGATRONS FROM PHOTO-ELECTRIC ELEMENTS

(1) It is a property of metals to shed or emit negatrons. The surface of any metal is always surrounded by an extremely thin cloud of negatrons which have escaped from that surface. The number of negatrons escaping from a square inch of metallic surface at ordinary room temperature is considerable, but since (as we have seen) a fantastically enormous number of negatrons is needed to constitute even a minute electrical charge or current, the electrical effect of the negatrons thus escaping is extremely small, and difficult to detect.

(2) If, however, the metal is heated to the point of incandescence, the emission of negatrons from its surface is vastly increased. (3) If this emission takes place in air, its effect is to ionize or disrupt the atoms of air immediately surrounding the emitting surface, the energy of the emission being consumed to no beneficial purpose. If free negatrons emitted by any metal are to be made useful, the emission must take place in a vacuum. Exceptions to the statement just made will be discussed later on. See Pages 506 and 518.

There is no practical way of raising the temperature of a metal to the point of incandescence, when the metal is in vacuum, except by passing an electric current through it. If the current be large enough, and the resistance of the metal high enough, incandescence is attained, just as in the case of any ordinary electric lamp filament. Negatrons are emitted by the filament of any incandescent lamp. However, they serve no useful purpose in the lamp. It will be worth while, nevertheless, to consider the life history of a negatron emitted from an electric lamp filament. The negatron, on leaving the filament, continues out through the vacuum by virtue of its initial velocity. The filament has become positive to the extent of the loss of one negatron. This positive charge of the filament exercises an attractive force upon the negative electron, slowing down its motion until it is brought to a full stop. The same attraction then draws the negatron back into the filament from which it had escaped.

(4) Now, if we consider the multitudes of negatrons emitted from the filament, it is clear that the filament will always, while it remains incandescent, be surrounded by a cloud of negatrons. Some will be just coming out of a filament. Some will have moved away from the filament to the maximum distance they can attain. Some will be moving back towards the filament and re-entering it. This cloud of negatrons surrounding an emitting surface constitutes a negative charge in the area of space or vacuum which it occupies. When it occurs within a vacuum tube, this charge is called a "space charge."

The practical uses of emitting filaments and of the space charge in vacuum tubes will be discussed on a later page. Here we are concerned only with incandescent metals as sources of negatrons.

(5) But it is very necessary to note that it is the metal which is the source of the negatrons, and not the current that is passed through it to heat it. In order that there may remain no doubt upon this point it may be desirable to pause now to describe the "heater" type of filament used in a number of vacuum tubes. The construction of this filament clearly shows that the incandescent metal and *not* the heating current is the source of emitted negatrons.

Heater Filaments

(6) The heater filament is found, for example, in the "27" type amplifying tube which is used in many sound systems and most radio receivers. The filament consists of a very thin, hair-pin shaped wire. This wire passes through, and is surrounded by, a substance which is an insulator of electricity but a moderately good con-

ductor of heat. The outer surface of this substance is coated with emitting metal, usually thorium. The heater current flows in one end of the hair-pin wire, around the hair-pin bend and out at the other end of the wire. It is insulated from and never touches the thorium, which serves as an emitter only because it becomes hot enough to give off a relatively large quantity of negatrons.

Cold Emitters

(7) Although tubes based upon that principle are seldom used in theatre equipment it may be of theoretical interest here to include a word about a tube that operates with a cold cathode or emitter. There is a tube used in some radios and a few theatres which consists essentially of two pieces of metal inside a vacuum. One of these metals has a very much larger surface than the other. Both metals, even though cold, emit some negatrons, but since the emission is proportional to the surface, the vastly greater emission from the metal with the larger surface can be made to constitute a current flowing across the tube to the metal with the smaller surface.

How emitted negatrons are made to flow across a vacuum to another element within the glass, and thus to constitute a current, is explained on Page 499. Here we are interested only in methods by which negatrons may be obtained.

Negatrons from Photo-electric Substances

(8) Certain metals which, like all metals, at all times emit a few negatrons, possess the property of increasing their emission when exposed to light.

(9) Caesium and potassium are two metals in which this property is most strongly apparent, and these metals are used as emitting surfaces in photo-electric cells.

This action is not nearly as well understood as emission depending upon heat. (10) The cause of increased emission in the case of an incandescent metal is readily explained. The molecules of every substance are at all times in a state of agitation. Increased temperature increases this agitation. Collisions between molecules occur. During some of these collisions negatrons become detached from their atoms. Often the attraction of the positive ion draws back the lost negatron to its source. But where the velocity of the motion of the negatron is relatively great, it may continue moving away from the atom until it has passed through the surface of the material and continued some distance out into the space beyond. The greater the agitation of the molecules, that is, the higher the temperature of the metal, the more frequently will negatrons be detached from their atoms with sufficient initial velocity to enable them to leave the material and enter into the surrounding air or vacuum.

Thus the action of incandescence in promoting increased emission is known because the nature of increased temperature in a metal is known. Increased temperature in a metal is simply increased agitation of the molecules. When this agitation becomes sufficiently great, both light and negatrons are emitted from the metal, which is then said to be incandescent.

But the fundamental nature of light itself is still a matter of conflicting theories, and until more is known about it the nature of electronic emission from photo-electric substances will not be wholly understood. All that can be said at this time is that when light falls upon a photo-electric metal, emission of negatrons from its surface is very greatly increased. The effect varies with the color of the light. It is also dependent upon the thickness of the emitting substance. In modern photo-electric cells the layer of emitting material is only one or two molecules thick, or less than one-billionth of an inch. (11) But why light has this effect upon certain metals is still far from clear.

NEGATRONS AND MAGNETISM

Magnetic Action, page 36

1. Can steel be magnetized permanently?
2. Can iron be magnetized permanently?
3. When does copper act like a magnet?
4. Are the attraction and repulsion manifested by positrons and negatrons toward each other *magnetic* forces?

Theory of Magnetism, page 37

5. What is the essential nature of magnetism?
6. Explain why the magnetism shown by a wire carrying current is the same force as the magnetism shown by iron or steel.
7. Explain why steel can be magnetized permanently, but iron only temporarily.
8. Under what circumstances can magnetism exist, but be so masked that it cannot reveal itself?

CHAPTER XXI

NEGATRONS AND MAGNETISM

Everyone is familiar with the ordinary steel magnet and its attraction for iron. A few simple facts about it may be repeated to refresh the memory of those who may have forgotten.

(1) Steel can be made into a permanent magnet. (2) Soft iron can be magnetized only temporarily. A bar of steel—the blade of a screwdriver, for example—can be magnetized by stroking it against a magnet, or by winding wire around it and passing current from a battery through the wire. A bar of soft iron, such as an iron nail, will also be magnetized when it is surrounded by wire carrying current, but only for so long as the current flows. When the current is turned off the iron loses its magnetic property.

All these facts are as important in electrical work as the fact that copper wire will conduct current. There is one more familiar point of special significance, which is emphasized here in order that it may stand out and not be overlooked or forgotten. It is this:

(3) Any conductor carrying current is a magnet while the current flows, even though there is no iron or steel near it.

Let current from a battery pass through a copper wire and a magnetic attraction will be exerted either upon small bits of iron, or upon a second conductor carrying current.

Magnetic and Static Fields

(4) The attraction and repulsion manifested by negatrons and positrons, described a few pages back, are not magnetic in any way. An electric charge repels its like charge and attracts its opposite. It shows, how-

ever, neither attraction nor repulsion for iron, and in other ways is altogether unmagnetic in its action. The attraction or repulsion associated with electric charges is spoken of as "static" or "electric." A field of static or electric force surrounds every electrical charge.

But a field of magnetic force surrounds every magnet, as well as every conductor carrying current. They are two entirely different forces.

Nature of Magnetism

(5) If a piece of hard rubber be charged by friction and mounted on the edge of a rapidly rotating wheel, the rubber so charged will acquire and maintain a magnetic field as long as the wheel continues to revolve. But we already know that any electrical current is only an electric charge in motion, and that every conductor is surrounded by a magnetic field as long as current continues to flow through it.

These facts would seem to indicate that magnetism is a property manifested by electricity in motion. (6) But if that is true there must be moving electricity somewhere inside a magnetized steel bar. Modern theory holds that such is the case. We remember that the atoms of every substance consist of positive cores surrounded by clouds of moving negatrons. Some substances, iron most prominently, are capable of becoming magnetized but are not always magnets; they can, however, be magnetized. Some substances cannot be magnetized. If half the negatrons in any molecule are revolving in one direction and half in the other direction, that molecule can never be magnetized. Each negatron is in itself a tiny magnet, but its magnetic effect is cancelled by that of another negatron which is moving in the opposite direction inside the same molecule.

But if most of the negatrons in a molecule are moving in the same direction, that molecule is always a magnet. A substance composed of such molecules can be magnetized. Normally the substance will be in unmagnetized condition, because the molecules will point in every direction and thus their magnetic forces will be in conflict. If, however, a strong magnetic field be imposed on such a substance by an outside agency, as by a wire carrying current or by stroking with a previously magnetized object, all the molecules will "fall in" along the magnetic lines of force, and the substance as a whole will be a magnet until the molecules again return to their haphazard positions.

(7) Soft iron will not retain its magnetism for the reason that there is nothing to hold its molecules in position once the external magnetizing influence is removed. Steel, however, consists of iron molecules rigidly held in a cement of carbon, silicon, or some other alloy. Steel is harder to magnetize than iron because the cement does not permit the iron molecules in the steel to change their positions very easily. Once magnetized, steel does not lose its magnetism easily for precisely the same reason, namely, that the alloy does not permit the molecules to fall back into their unmagnetic arrangement. A steel magnet will often retain its power for many years.

(8) Magnetism, then, is a property exhibited by negatrons whenever they are in motion. It may be masked, however, as in unmagnetic substances, or in unmagnetized iron, by the motion of an equal number of negatrons in an opposite direction. Thus, a steel screwdriver blade cannot be magnetized by winding around it a pair of wires in which the current flow is opposite. The magnetizing effect of one wire will be cancelled by the influence of the other.

MAGNETIC GENERATION OF CURRENT

The Electric Generator, page 460

1. Why does motion in a magnetic field generate a flow of current in conductor lying within that field.
2. Why cannot direct current be generated in this way?
3. If direct current cannot be generated magnetically, how is it that d.c. is drawn from the brushes of a d.c. dynamo?

The Electrical Transformer, page 461

4. Can current flow be generated in a conductor lying within a magnetic field without any physical motion? What is the name of the instrument that does this?
5. Can d.c. be drawn from a transformer?
6. Describe the construction of a transformer.
7. What are the primary and secondary windings of a transformer?
8. Explain voltage "step-up" and "step-down" in a transformer.

CHAPTER XXII

MAGNETIC GENERATION OF ELECTRIC CURRENT

(1) Imagine a steel magnet lying on a table near a piece of copper wire. Copper wire is a conductor, therefore it contains either "free" negatrons, or negatrons easily detached from their atoms. If either the magnet or the wire be moved, the influence of the magnetic field upon the negatrons within the copper will cause those negatrons to move into new positions. While they are doing this they of course constitute an electric current, since for that brief period of time they are negatrons in motion.

If the motion of either the magnet or the conductor can be made continuous, the motion of the negatrons within the conductor will also be continuous, and a steady current will flow.

The Electric Generator

In another part of this book (see Page 295) there will be found a description of the mechanism of a generator, which is one device by means of which current flow is created through motion of conductors in a magnetic field.

(2) As a matter of practical fact, continuous or direct current cannot be generated by motion in a magnetic field. If the motion were to continue in the same direction for any appreciable length of time the conductor and the magnet would soon be so far apart that the magnetic influence could not operate. Therefore a motion that causes the conductor to cut through lines of force in the magnetic field without taking the conductor out of the field must be arranged, which is done by making the conductor alternately approach and recede from the magnet, and the current generated by magnetic

action periodically reverses its direction of flow. It is therefore called "alternating current."

(3) Direct current is drawn from an alternating current generator (all generator armatures create alternating current) by means of a mechanical "rectifier" called a "commutator," which is described on Page 297.

This method of generating a flow of negatrons (the negatrons are not created; all that hapens is that motion is imparted to negatrons existing in the conductor) depends upon the fact that motion, either of the conductor or of the magnet, changes the magnetic force acting upon the negatrons. Therefore it should be possible to generate current flow without physical motion, merely by changing the strength of a magnet. This can be done with an electro-magnet, and the device that does it is called a "transformer."

The Electrical Transformer

(4) A wire carrying current is a magnet. Place another wire alongside it. Call this second wire Wire "B," and the wire carrying current Wire "A." Then we have the same condition as above, a magnet placed near a conductor. Now so long as the current flowing through Wire A remains steady and unchanged in strength, there will be no change in the influence of the magnetic field upon the negatrons in Wire B, but the moment the strength of the current through Wire A changes, the negatrons in B take up new positions, and while in the motion of doing so they constitute an electric current.

It is obvious that the strength of the current in Wire A can only be changed either by increasing or decreasing its volume. It cannot increase in strength forever; neither can it decrease forever without reaching zero. Precisely as in the case of current generated by means of physical motion in a magnetic field, the generation of current by means of change in the strength of an electromagnet must result in change of direction of flow—in the creation of alternating current. (5) D. c. cannot be drawn from a transformer.

(6) The transformer consists, for all practical purposes, of a coil of wire (Wire A) placed close to another coil (Wire B). In transformers used in the projection room these two coils will be wound upon the same iron core. For some purposes, radio receivers, for example, iron cannot be used in a transformer, by reason of the fact that reversal of direction of the current is so rapid that the motion of the molecules of the iron (which of course is magnetized) cannot keep pace with it. But for all light source control purposes and in most sound equipment iron-core transformers are the rule. They are able to handle vastly more power than would be possible if the iron were not present.

Transformers and Voltage Change

(7) In a transformer, the winding of wire just spoken of as Wire A, which carries the magnetizing current, is called the primary winding. Wire B represents the secondary winding.

(8) A one-volt drop across one complete turn of primary wire will induce a one-volt drop across one complete turn of secondary wire, therefore if the primary consists of one turn of wire carrying one ampere of curent at one volt, and the secondary consists of two turns of wire, the current in the secondary will be ½ ampere at two volts for the secondary as a whole. In the same way, if the primary power is 110 volts, the secondary power can be made 220 volts at one-half the current. Or, by connecting the transformers the other way around, the secondary output can be made 55 volts, at twice the current. Any voltage "step-up" or "step-down" can be secured by means of a transformer. A transformer can also be made with one primary and a number of secondaries, each delivering a different voltage.

Since transformers, as explained above, cannot work with direct current unless it be pulsating, these convenient voltage changes are unfortunately impossible with the smooth d. c. drawn from a battery or a commercial power line. In some sound systems, where it is necessary to obtain high voltage direct current, and only low voltage direct current is available, the low voltage supply must first be converted to a. c., the a. c. then stepped up by a transformer to the required high voltage, and the high voltage a. c. thus secured again rectified to high voltage direct current. We shall study some examples of this process a bit later on.

CHARACTERISTICS OF ALTERNATING CURRENT

Theory of the Electrical Condenser, page 465

1. Does any current at all flow through an open switch in a d.c. circuit? In an a.c. circuit?
2. Explain why a small amount of current flows in the wires of an a.c. circuit even when the switch is open.
3. What is the effect, upon this weak current flow, of moving the switch blades closer to the contacts connected with the other side of the line?

Construction of the Electrical Condenser, page 466

4. Describe an electrical condenser, and explain its action in an a.c. circuit.
5. Describe the construction of an electrolytic condenser.
6. Can it be used in an a.c. line?

The Induction Coil, page 467

7. Describe an induction coil.
8. Describe a retard coil.
9. Describe the action of an induction coil in a d.c. circuit. In an a.c. circuit.

Ohm's Law for Alternating Current, page 468

10. Does the formula of Ohm's Law for d.c. also apply to a.c.? Why not?
11. What is reactance?
12. What is impedance?
13. Give the formula of Ohm's Law for a.c.
14. Explain the difference between this and the d.c. formula, and the reason therefore.

CHAPTER XXIII

CHARACTERISTICS OF ALTERNATING CURRENT

(1) The switch in a light circuit will extinguish the light, whether the power be a. c. or d. c. But if the lamp bulb is removed from the socket and a sensitive meter substituted, the instrument will show that in an a. c. line a very weak current continues to flow in spite of the open switch, while in a d. c. line this does not happen. If we examine what the negatrons are doing in the vicinity of the switch this seemingly strange fact is readily understood.

(2) Consider the switch in a d. c. line. Suppose the switch to be open. Negatrons from the negative source occupy the negative side of the switch. Free negatrons from the positive blade have been drawn away toward the positive source of power. Now if the switch be partly closed there will be an additional flow, because, as the negative and positive charges come closer (the switch more nearly closed) more negatrons will be attracted to the negative blade. A corresponding number of negatrons will be repelled from the positive blade and will move back towards the positive source of power. During the course of this small change there of course is a slight movement of negatrons, which is the same thing as a slight flow of current, in both of the wires.

If, now, the switch be left alone and the d. c. voltage does not change, there is no reason for any further motion of negatrons, and hence there is no further flow of current.

With this in mind it is easy to see that when a. c. is connected to an open switch there is always some slight flow of negatrons in the wires. The switch blades periodically reverse polarity, therefore negatrons are constantly flowing into one and out of the other, reversing this procedure so many times a second, according to the frequency of the alternating supply. The result is a very slight but endless surging of current in the wires leading to the switch.

(3) Now if the switch be partly closed, this slight flow of current will be increased, because a greater number of negatrons will be attracted to the negative blade and a greater number of them repelled from the positive blade. The closer the blades, the greater the flow of current will be, though in any event it is of course too weak to be detected by anything but a very delicate galvanometer.

Sometimes it is desirable to include in a circuit a device that will permit the effect of alternating current flowing, while at the same time preventing the passage of any direct current. Such a device is an "open switch," constructed of two pieces of metal placed very closely together, but kept from touching by some efficient insulation such as mica or paper. The thinner the insulation—the more nearly the "switch" is closed—the greater the amount of alternating current that will move in the wires, although as just explained negatrons do not in fact move through the insulation. A still greater flow of alternating current is obtained by increasing the dimensions or surface area of the conductors at the point where they face each other, because the larger this area the greater the number of negatrons that will be attracted into the negative and repelled from the positive plate.

The Electrical Condenser

(4) A device of this kind is called a condenser. Its action is precisely the same as that of an open switch in an a. c. line. In commercial form it consists of very large areas of metal or tin-foil, separated from each other by extremely thin layers of either treated paper or of mica. (5) Another commercial form uses a plate of aluminum separated from a conducting liquid by a chemical layer deposited on the aluminum. This latter

type is called an "electrolytic condenser." (6) It cannot, however, be used with alternating current, since reversing the polarity of its connections destroys the insulating layer. It is used for certain purposes which will be described later in connection with direct current circuits. See Page 476.

The Induction Coil

(7) Remember that an electro-magnet consists of a wire carrying current. In its commercial form it is a coil of insulated wire. The coil is very often wound around a soft iron core (which of course is magnetized), since an iron core greatly increases the power of the magnet.

Such a winding is called an "induction coil," as well as by several other names, some of which are "inductive winding," "choke coil," (8) "retard coil" and "inductor." (9) When current is first applied to such a winding it immediately finds work to perform in moving the molecules of the iron into magnetic positions. Once this has been done the current flow increases greatly, since the haphazard magnetic fields of the iron molecules no longer resist its passage. When the switch is opened the molecules fall back into their original, unmagnetic positions, and in so doing the motion of their magnetic fields generates a reinforcing current in the wire.

Direct current flows through such a coil without difficulty as soon as it has moved the iron molecules into their magnetic positions, but alternating current causes the molecules to reverse their line-up periodically, hence meets much more opposition from them than would direct current. Consequently, if the condenser is a device that can be said to allow a. c. but not d. c. to flow through it, the inductor is a device that allows d. c. but not a. c. to pass. As the condenser is sometimes used to pass a. c. but prevent the flow of d. c. the inductor is occasionally used for the reverse purpose.

Ohm's Law For Alternating Current

(10) In a d. c. circuit the amperage flowing is equal to the voltage driving it divided by the resistance of the conductor, as we have already seen, but in an alternating current circuit there are other factors besides the resistance of the conductor which tend to oppose the voltage and hold back the flow of current. (11) Both inductances and condensers oppose the passage of alternating current through them to some degree, and their opposition, their resistive effect, is called reactance.

Therefore in applying Ohm's Law to an alternating current circuit we must take reactance into consideration in addition to the usual resistance of the wire. The principle behind Ohm's Law holds precisely as true for a. c. as for d. c. but the details of the formula must be changed to allow for the effect of reactance.

(12) The term impedance is used in connection with a. c. circuits to designate the effect of both the conductor resistance and the inductive and capacitative reactance, in other words, the sum total of all the influences tending to oppose the flow of current. Therefore in a. c. circuits Ohm's Law is $I = E \div Z$ (impedance) or

$$(13)\quad \text{Current} = \frac{\text{Voltage}}{\text{Impedance}}$$

just as the d. c. law reads

$$\text{Current} = \frac{\text{Voltage}}{\text{Resistance}}$$

(14) The only difference between these two forms of the same law is that in the case of d. c. there is no reactance and the resistance and the impedance are the same thing, while in the case of a. c. the impedance is more than the wire resistance alone.

THE A.C. TRANSMISSION LINE

Impedance Match, page 470

1. Name an important requirement in a circuit carrying a.c.
2. Explain the necessity for impedance match.
3. Why is impedance match of especial importance in sound circuits?
4. Where and why may impedance mis-match be intentionally introduced into a sound system?
5. At what frequency are impedances matched in sound equipment?

Components and Resultants, page 472

6. Can two distinct currents travel in the same wire?
7. What is a resultant?
8. What is a component?

Electrical Filters, page 475

9. What is an electrical filter?
10. Explain the use of a "brute force" filter.
11. Explain the action of "brute force" filters.
12. How many low and high frequencies in the same wire be separated?
13. What is a "low-pass filter"?
14. What is a "high-pass" filter?
15. How can the selective effect of a filter be modified?
16. How are low-pass and high-pass filters used in sound apparatus?
17. Describe a "resonant circuit."
18. What are "band pass" filters?
19. Which type of filter is most often found in the projection room?

CHAPTER XXIV

THE A C TRANSMISSION LINE

(1) When a. c. is transmitted over a pair of wires, one of the most important requirements of the circuit is that the impedance (see Page 468) of the apparatus from which the current comes shall match the impedance of the apparatus to which the current is led. (See

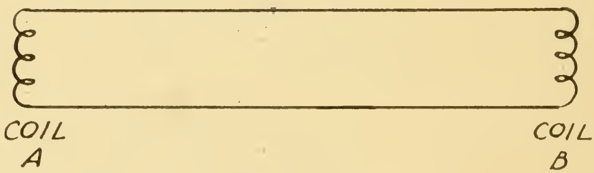


FIGURE 106

IMPEDANCE MATCH

Figure 106 represents a very simple a. c. transmission line, in which we assume that the source of the current is coil A. Coil A may be, and in sound equipment usually is, the secondary winding of a transformer. Coil B may be the speech winding of a loud speaker or the primary winding of an input transformer or other apparatus. In any case, the impedances of A and B should be identical. There are a very few exceptions, none of which need concern the projectionist.

(2) We can most easily understand the necessity for impedance match between A and B by assigning numerical values to their action. Let us assume that A has an impedance of 1000 ohms and that it is the secondary of a transformer developing 100 volts. Now assume that the impedance of B also is 1000 ohms. Let us calculate the amount of power transferred from A to B.

The total voltage of this circuit is 100, of which 50 volts is consumed by the loss or drop in coil A. Therefore, neglecting the resistance of the connecting wires, 50 volts must be the drop across coil B. The circuit current is, by Ohm's Law (100 ÷ 2000 ohms), 1/20 of an ampere. Then the power in coil B is 1/20 of an ampere times 50, or 2½ watts.

Now the reader may please himself by assigning other impedances to B and he will find that no impedance except that which equals the impedance of coil A will give him as much as 2½ watts in coil B. By trying one or two examples we will easily see the reason for this. Suppose we make B 500 ohms. Then the total impedance of the circuit is 1500 ohms and the current flowing is, by Ohm's Law, 100 divided by 1500, or 1/15 of an ampere. 1/15 of an ampere is a larger current than 1/20 of an ampere. We now have more current in coil B than before, but let us see about the power. Coil B now has only 1/3 of the total impedance of the circuit and the voltage drop across it is only 33 1/3 volts. If the reader will apply elementary arithmetic to these figures he will find that the power in coil B is now only 33 1/3 multiplied by 1/15, or 2 2/9 watts. The current flow through B has been increased but the voltage drop across coil B has been reduced, and the power in any resistor is the current flowing multiplied by the voltage drop.

If, on the contrary, we make B 2000 ohms, then there is a 66 2/3 volt drop across B. But the increased impedance has reduced the current flowing in the circuit to 1/30 of an ampere, and the power in B is again only 2 2/9 of a watt. The reader may make as many other calculations as he cares to, assigning any value of impedance whatever to coil B. He will invariably find that either the decreasing current in coil B or the decreased voltage drop across it reduces the power in that winding to some figure less than the 2½ watts obtained when the impedances were accurately matched.

(3) Impedance match is of great importance in sound systems, where the alternating currents representing speech are often extremely minute and any loss

of power anywhere in the system seriously reduces the volume that can be obtained from the loud speaker. (4) In a few systems a variable impedance mis-match is intentionally introduced as a means of volume control, and for other purposes, such as control of the frequency response of the system.

The impedance of an a. c. circuit is partly a matter of the reactance, that is, of the resistive effects of inductors or capacitances. Now the reactance of these devices varies with different frequencies of alternating current, and sound currents may be of any frequency between 16 and 16,000 cycles per second. Therefore it is not always possible to match impedances for all sound frequencies. (5) A practical compromise is effected in sound apparatus by matching impedances over the widest possible band of those frequencies to which the ear is most sensitive. The impedance rating of any piece of sound apparatus commonly means the impedance of that part to a. c. of 1,000 cycles. Then its impedance to 500 or 1,500 cycle current will not be very much different, while its impedance to currents of 100 or of 10,000 cycles may be distinctly different.

The highest possible quality and efficiency are obtained by carefully maintaining impedance match at some central and important frequency, such as 1,000 cycles, except where an intentional and carefully calculated mis-match is introduced for some such purpose as reinforcing or suppressing a selected band of frequencies.

Components and Resultants

(6) In another part of this book (see Page 20) two and three-phase current are discussed. The existence of such currents shows that two different and separate alternating currents can travel in the same pair of wires. Sound currents vary in frequency. A violin may strike a note of, say, 1,280 cycles at the same time that a piano is sounding a note of 960 cycles. These two sounds are created and heard simultaneously. The two different frequencies of alternating current that repre-

sent them travel simultaneously through the wires of the sound projection equipment. Figure 107 is a diagram illustrative of the effect of two different frequencies traveling simultaneously in the same wire. It may

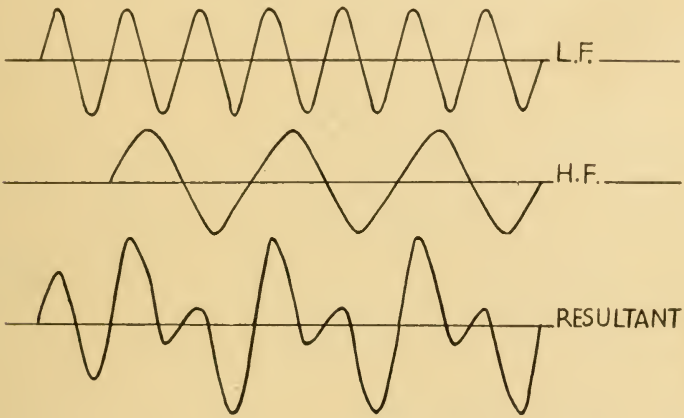


FIGURE 107.

be helpful to describe Figure 107 in terms of what actually happens to the negatrons in the conductor.

Let it be supposed that the violin string is sounded first and while it is still giving off 1,280-cycle sound the piano key is struck. At first 1,280-cycle alternating current will travel alone through the wires of the sound system. As the piano note comes in a second frequency is superimposed upon this. Sometimes the piano negatrons will be moving in the same direction as the violin negatrons, and the total current flowing through the wires will be increased accordingly. Sometimes the piano negatrons will be attempting to travel in the opposite direction to the violin negatrons and the mutual opposition of these two voltages will result in a greatly decreased flow of current in the wires.

We may think of such a wire as carrying two distinct and separate frequencies which do not interfere with each other, and this method of thinking about what happens is in many ways of practical advantage. But we may also say that the wire at any time carries only one current, that current being the (7) resultant of the two forces (8), or components, existing in the wire. This is just another case of two different theories, either of which may be correct (although the second is more probably the true one) but each of which is useful in a different way, according to what we want to do with the circuit.

A. C. and D. C. Resultants

Suppose an a. c. generator and a d. c. generator are connected in parallel to the same power line. This is not done in power transmission, of course, but it very much resembles what happens in many parts of a sound system. The effect may be thought of as two currents traveling in one wire; also may be thought of as creating a resultant which is in effect a pulsating direct current

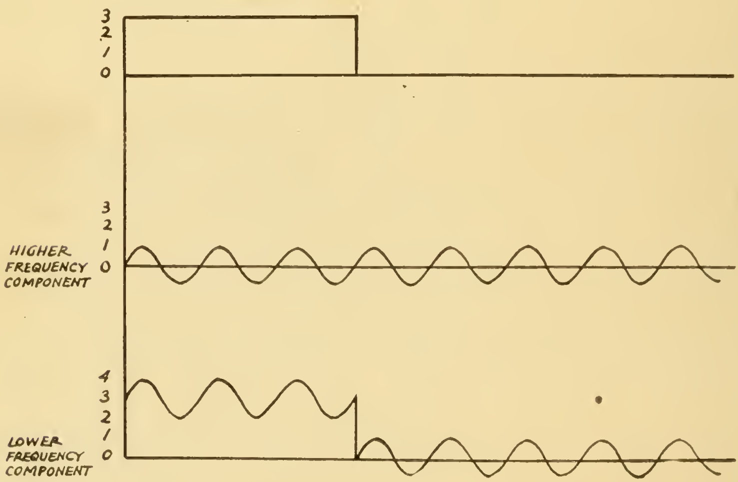


Figure 108

(see Figure 108). In other words, when the a. c. is flowing in the same direction as the d. c., the total current through the wire is greatly increased; when the direction of the a. c. flow opposes that of the d. c., the current in the wire decreases accordingly. If the alternating current is stronger than the direct, the resultant will be an alternating current which is much stronger in one direction than in the other. In Figure 108, the d. c is stronger than the a. c.

Electrical Filters

(9) When two different currents flow in one wire that branches into two parallel circuits (see Fig. 109) the currents can be separated and each made to flow

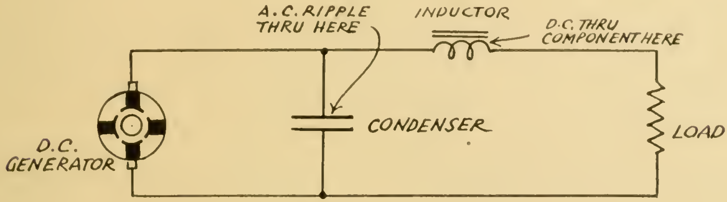


Figure 109

along one of the branches. The apparatus which performs this separation is called a filter and consists of either inductors or capacitances, or of both together.

For example, in the case of direct and alternating current flowing in the one wire, one of the two branches forking from this wire may contain an inductor in series with it, the other a capacitance or condenser. The direct current then will complete its circuit through the inductor, since it cannot flow through a condenser. The alternating current, which has great difficulty flowing through an inductor, will (as explained on Page 467) complete its circuit through the condenser. (See Figure 109.)

"Brute Force" Filters

(10) On Page 12 will be found a description of a commutator, a rectifying device by means of which direct current is obtained from a dynamo, although only alternating current can be generated in its armature. We shall later see that other rectifying devices of very different construction are used in connection with sound systems to convert line a. c. to smooth direct current. No rectifying device produces d. c. as smooth and steady

as that drawn from a battery. In every case there is some ripple or irregularity left in the d. c. obtained from any rectifier, and this ripple, as we have just seen (Figure 108) may be regarded as the resultant of d. c. and a. c. flowing in the same wire. Therefore such current is compelled to pass through an inductor before it reaches the point where it is to be used, while a branch path is provided and equipped with a condenser. The d. c. flows through the inductor and the a. c. component or ripple takes the branch path through the condenser. This arrangement constitutes one "stage" of a "brute force" filter. If additional filtering is needed, two or more stages may be used (see Figure 110).

(11) As we have just said, the action of a brute force filter may be thought of as separating two currents

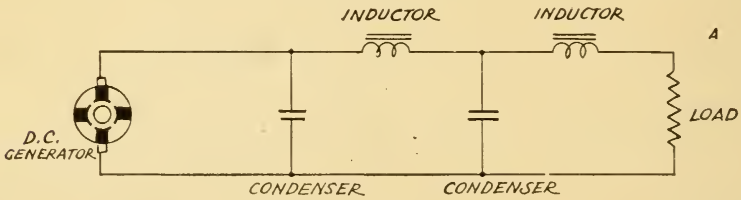


Figure 110

flowing in the same wire, which is the most convenient way of regarding what happens. But it is equally possible to look upon the wire as containing only one current, which is the resultant of a strong d. c. and a weak a. c.—in other words, d. c. with a slight ripple. We may say that what happens when the d. c. increases in strength is that some of the increased power is absorbed by both the increased charge of the condenser and the increased magnetization of the inductor. When the d. c. declines in voltage the condenser gives back some of its charge to the line, and the return of some of the molecules of the iron to their unmagnetic positions generates a reinforcing current in the wire. Thus the condenser and the inductor both act to rob the line of some current during its maximum flow and to restore current to the line during minimum flow. In still other words, the brute force filter cuts off the tops of the waves and uses them to fill in the troughs. The net effect is that a smooth direct current flows through the device in which the current is to be used.

Frequency Band Filters

(12) A circuit may be arranged exactly as described above to separate low frequency from high frequency a. c. In that case the reactance of the inductor is reduced to a point where some a. c. will be able to flow through it. The lower the frequency (the longer the time during which the current continues flowing in one direction) the more freely will a. c. be able to pass through the inductor. Conversely, the higher the frequency, the oftener the current reverses its direction, the greater will be the charge and discharge per second—or apparent flow of a. c.—through the condenser.

If this circuit is so arranged that the path through the inductor leads to the place where the power is to be used while the path through the condenser is a mere by-path to the return, (13) the arrangement is called a low-pass filter, because it admits or passes only the lower frequencies to the place where the power is to be applied. (14) On the other hand, if the circuit is so arranged that the condenser is in series with the apparatus in which the power is used and the inductor is merely a by-pass to the return line, the arrangement is called a high-pass filter, because it permits only the higher frequencies to reach the apparatus for which the power is intended. In either of these circuits power is of course lost. Either the low frequency or the high frequency is by-passed to the return without traversing any apparatus in which it performs a useful function.

Such is the commonest form of selective filter, but sometimes apparatus is included in series with the by-pass circuit and then both the low frequency and high frequency power are usefully employed. This is the case where more than one type of loud speaker is used in a modern sound system. If there is both a low frequency and a high frequency speaker, the one is wired to the amplifier output through what is essentially an inductance, and the other through a condenser. Either the inductance or the condenser may stand alone or may operate in conjunction with other inductors or condensers. (15) Also the selective effect of either may be modified by the addition of a variable resistor.

(16) Low pass and high pass filters are also used as tone controls to emphasize or eliminate either low or high notes. They can be made variable in their action by a number of simple modifications, the most common of which is the inclusion of a variable resistor.

(17) Special narrow band filters are of more complicated construction and action than those described above. They require at least two inductors and two condensers and are essentially "resonant" circuits in which the rhythmic rise and fall of the inductor fields and the periodic charge and discharge of the condensers cooperate either to reinforce or to oppose any one band of frequencies, according to the values of inductance and capacitance chosen. (18) Such filters can compensate for defects in quality by accentuating ("band pass") any note or band of notes without appreciable effect upon any other frequencies, whether lower or higher. Band pass filters of this last type are, however, not very often encountered in sound systems. Sometimes, when three types of loud speaker are used, low-frequency, middle-frequency and high-frequency, a band-pass filter of the kind just mentioned is used to admit current to the middle frequency speaker. (19) Most frequency filters encountered in the projection room are, however, low pass or high pass arrangements consisting of more than one stage of filtering to secure more efficient results. Even these are comparatively rare. By far the most common projection room filter is the brute force arrangement designed to remove ripple from rectified d. c. This is found in practically every projection room.

COMPONENT PARTS OF A SOUND SYSTEM

The Sound System as a Whole, page 481

1. Why is a sound system frequently divided into many different panels and cabinets?
2. Does this division correspond to technical differences in the nature of work performed?
3. Divide a sound system into six parts according to the technical functions of the apparatus.

The Sound Pickup, page 482

4. What is the function of the photoelectric cell in a sound system?
5. Name two other sources of sound current.

The Transmission Lines, page 482

6. What is the function of transmission lines in a sound system?
7. Are they found inside as well as outside amplifiers or other apparatus?
8. What is the minimum number of external transmission lines in any sound system?
9. Can ground be used as one side of a transmission line?

The Amplifiers, page 483

10. Does an amplifier act to convert weak currents into strong ones?
11. Is the output current drawn from an amplifier only the input current made stronger?
12. When speech current is supplied to an amplifier, does it complete its circuit back to its source as ordinary currents do?
13. Describe in outline the process of amplification in an amplifier of several stages.

14. What apparatus in an amplifier functions as an electrical valve, or controller?

THE SPEAKERS, PAGE 485

15. Explain the difference between a loud speaker and an ordinary electric motor.

THE POWER SOURCES, PAGE 485

16. What type of electrical power is required by sound systems?
17. How is this obtained from ordinary line a.c.?
18. Name two classes of circuits found in a modern amplifier.
19. Why do sound reproducing systems require a mechanical drive?

THE DRIVES, PAGE 486

20. Name some of the devices in a sound installation that may be classified under the heading of "The Drive System."

CHAPTER XXV

COMPONENT PARTS OF A SOUND SYSTEM

In studying the application in a practical sound system of the theories already outlined and of one or two others still to come, it will be exceedingly helpful to divide up the sound apparatus into its component parts. Such division will not necessarily follow the manufacturer's division of his equipment into different panels, cabinets, etc.

(1) The manufacturer splits up his equipment into small units primarily for the convenience of the projectionist, but also to facilitate shipment and installation. (2) He does not divide it in accordance with the technical uses of the parts, but rather for the comfort of the expressman; to secure convenient layout in the projection room, and to make repair or replacement as simple as possible. In studying the functioning of any given installation of sound equipment the projectionist will find it advantageous temporarily to forget its physical division into cabinets or panels and to concentrate upon an electrical whole subdivided, in his mind, according to the functions the different parts perform, regardless of whether two parts that do the same work are in different cabinets or whether two parts that do different work are in the same cabinet. Later, when he is thoroughly familiar with the theory and behavior of every portion of his equipment, he will reap great advantage in trouble-shooting by considering the manner in which the system is divided up physically, and the most convenient points for reaching connecting terminals to which test instruments can be applied.

For the present, we are concerned with dividing up the cumbersome whole of a sound system according to the different functions performed by its different parts.

From this point of view any sound installation consists of six parts, which are (3) as follows: (a) the sound pick-up; (b) the transmission lines; (c) the amplifiers; (d) the speakers; (e) the power supply; (f) the drive system.

The Sound Pick-up

(a) This consists of any or all sources of sound currents which are to be amplified and converted into sound by the loud speaker.

The most common of these is the photo-electric cell. (4) This cell acts to produce sound currents corresponding with the variations of light and darkness photographed upon moving film. Its action is described in greater detail on Page 515. (5) Another source of sound power is the disc reproducer or phonograph pick-up which creates currents that correspond to the irregularities of the groove engraved upon a phonograph record. Less common than either of these in theatre use is the microphone which is an instrument creating currents that correspond to any vibrations in the air that is in contact with its diaphragm. All these devices are explained more thoroughly on appropriate pages.

The Transmission Line

(b) Some of the electrical principles involved in the action of an a. c. transmission line were described in the preceding section. (6) Transmission lines are part of every sound system. They receive the current produced by the sound pick-up and carry it to the amplifier, with perhaps an intermediate stop at a change-over device or volume control. They carry the sound output of the amplifier to the speakers. (7) The interior of the amplifier contains, between its various parts, transmission lines which are electrically similar to external transmission lines, since wires carrying sound currents within the amplifier are subject to the same rules as wires carrying sound currents from one amplifier to another, or from an amplifier to a loud speaker.

Internally as well as externally impedances must be matched and frequency filters may or may not be inserted.

(8) The simplest possible sound system will have at least three external transmission lines: namely, one from each photo-electric cell to the amplifier and one from the amplifier to the loud speaker.

(9) Ground is sometimes used as one side of a transmission line, that is, as one of the two wires of the circuit. This procedure is rather common in photoelectric connections.

Amplifiers

(c) As we have already seen by several examples, the same electrical action can be looked upon in two different ways, according to convenience; and one of these ways of regarding any electrical action, even though known to be wrong, may still be useful for some purposes.

(10) In describing the action of amplifiers it is incorrect, but convenient, to say that an irregular alternating current, which corresponds in its various frequencies to waves of sound, enters an amplifier as a weak current and emerges from it strengthened, or "amplified."

The above statement, although very often made, is not strictly correct. It describes quite accurately what an amplifier does, but it gives a completely false impression of how the amplifier does it.

It is quite true that a weak alternating current enters the amplifier, and that a much stronger alternating current can then be taken from the output end. It is also true that the output current reproduces very nearly, and sometimes almost exactly, the input wave-form. (11) But the output current is not the input current made stronger. Instead, it is a totally different current, flowing through an entirely separate circuit. Although the construction and functioning of amplifiers are described in great detail further along, it should be worth while to take time at this point to explain just what an amplifier does not do, as well as what it does.

We have just seen what it does not do. It does not make a weak current stronger. It does use a weak current to operate a very delicate valve by means of which a much greater amperage is turned on or off and increased or decreased. The result is that the fluctuations thus introduced into the flow of the heavier amperage represent an exact or nearly exact reproduction of the current fluctuations of the original or input circuit.

The details of how this is done belong in another place. We merely note here (12) that the sound current flowing into an amplifier completes a normal electrical circuit back to its source just as any other current does. (13) Only, while in transmission, it passes through a valve apparatus in which it is enabled to exercise a very delicate control over the flow of current in a circuit of greater power.

Let us agree to call the input circuit P and the heavier circuit Q. Then if further amplification is needed Q can be used to operate another valve and thus control a third, still more powerful circuit, which we will call R. And R, in turn, can be used to operate the trigger controlling a yet heavier current, and so on. The process can be and often is repeated six or seven times. Nevertheless P, Q, R and all the other speech currents in an amplifier each return to their own source unchanged, in the normal electrical way. The only essential difference between amplifier wiring and any other electrical wiring is that each speech current, as it flows around its circuit, is made to pass through a valve in which it controls a stronger current.

(14) The valve, as it is called in England, is, of course, the tube. Our own word "tube" really means nothing except that the first devices of the kind, about twenty years ago, were built into long, slender tubes of glass instead of the bulbous glass envelopes of the present day. If the reader cares to make a habit of thinking of amplifying tubes as valves, his understanding of their action may perhaps be clarified.

A modern amplifier contains many other appliances beside its tubes, but all other parts are merely assistant pieces, put there to help the valves carry out their function.

All the parts that go to make up an amplifier, with their separate purposes and their interconnections, will be described in full detail a little later on. Here we are primarily interested in dividing up a complete sound system into its constituent units, of which the amplifier is only one.

Speakers

(d) The relatively powerful sound current drawn from the output circuit of an amplifier cannot be detected by human ears until it is converted into air vibrations of corresponding strength and frequency. (15) The apparatus that performs this conversion is the speaker, which is most easily understood by remembering that it is really an electric motor, driven by electrical power and producing mechanical power in the form of air waves. Most electric motors create mechanical power in the form of rotary motion. They turn a wheel. The speaker is a motor not designed to turn a wheel, but to operate a piston. The piston, of course, is the diaphragm of the speaker, which operates upon the surrounding air at the frequency, and in accordance with the strength, of the current driving it. Speakers also will be described, in detail, in their proper place.

Power Sources

(e) Every sound system requires power to operate it, (16) particularly direct current at both low and high voltages. Modern amplifiers often operate by simple connection to an a. c. power line, but a. c. at commercial line voltage does not enable them to perform their work, therefore (17) within the amplifier itself that power is converted to d. c. of suitable voltage and amperage.

Now, this work of power conversion is no part of the function of an amplifier. It is performed inside the amplifier casing only as a matter of convenience in construction and operation. In many of the earlier sound systems some, or perhaps all, of the power conversion is performed outside the amplifiers, which in such case have nothing to do except amplify. If the reader will always and invariably make this distinction in his mind he will find his study of amplifier circuits immensely simplified. He will then avoid any possible confusion between the amplifying valves and their attendant apparatus, which perform one job, and the power conversion apparatus, inside or outside the amplifier casing, which does another and entirely different piece of work. Later on, when we come to analyze amplifier drawings, this distinction will be made, since it will immediately simplify some of the complication of modern amplifier blueprints by dividing them in half, each half to be analyzed separately. (18) In working on modern amplifiers (trouble-shooting or repair) the reader will find it helpful to distinguish clearly between the speech circuits and the power circuits; doing so will take most of the difficulty out of his work.

(19) The above classifications include all the purely electrical portions of a sound system, but leave the mechanical parts to be considered. Sound is a sequence of events that can be made to create a mechanical or photographic record. This record can be made to produce, or "reproduce," a very close duplication of the original sound, provided it is fed into the reproducing mechanism bit by bit, exactly as it was made and at exactly the same speed.

A phonograph needle takes sound from a record bit by bit, but the original sound will not be duplicated accurately unless the record is played at precisely the same speed at which the recording was made. The film that excites the photoelectric cell must likewise be run through the projector at exactly the same speed at which the recording negative was made.

Drives

When the sound system operates from a microphone it is reproducing original sound, hence no driving apparatus of any kind is required. But when it reproduces a record, whether film or disc, it requires a driving motor to move the record at precisely the proper rate of speed. (20) Gears, belts or shafts are always used to transmit the motor power. Special governors may be employed to keep the motor speed constant in spite of accidental changes in the voltage of the power line that drives it. Mechanical devices of various kinds keep the record moving smoothly under the needle and keep the film moving precisely in its proper place before the photo-cell. All these contrivances, taken together, may be said to constitute the sixth, and perhaps the most important part, of a complete sound installation.

POWER SUPPLY FOR SOUND SYSTEMS

Varieties of Power Needed, page 490

1. List roughly the varieties of electrical power needed to operate an average sound system.
2. Is a loud-speaker field ever operated by alternating current?

Methods of Providing Power, page 491

3. For what power supply purposes may dry cells be used?
4. Why cannot power line d.c. be used to supply 90-volt d.c. to a photo-electric cell?
5. For what sound purpose can line d.c. be used, and how?
6. What auxiliary apparatus is used with a motor-generator supplying sound power?

How to Read Electrical Drawings, page 492

7. What is the most convenient way of studying any sound circuit?
8. What is a schematic drawing?
9. What is the difference between a schematic drawing and a wiring drawing?

Storage Battery Chargers, page 496

10. What apparatus serves as a battery charger when a battery is charged by means of a d.c. line?
11. Can a.c. be used as charging current? Why not?
12. What must be done to a.c. before it can be used to charge a storage battery?
13. Can a motor-generator be used to charge a battery?

Rectifier Tubes, page 498

14. How are rectifier tube filaments heated in a typical a.c.-operated battery charger?
15. Describe the internal construction of a rectifying tube.
16. Draw and describe its plate circuit in a typical battery charger.
17. What happens inside a rectifying tube when its plate charge swings positive with respect to its filament? When the plate swings negative?
18. What does a rectifying tube do when operated with a.c.-supply to its plate?

Half Wave and Full Wave Rectifiers, page 500

19. What is a half-wave rectifying circuit?
20. What is a full-wave rectifying circuit? Describe its action.
21. Compare a sound power supply rectifier with an a.c.-operated battery charger.

Power Supply Rectifier Circuit, page 501

22. Explain the circuits and action of a typical sound power supply rectifier (figure 115).
23. Draw the circuit of a typical "brute force" filter.
24. Why does a loud-speaker supply circuit need less filtering than a photo-electric supply circuit?

The Care of Tube Rectifiers, page 505

25. What attention and care must be given to the relay contacts of a power supply rectifier?
26. What common electrical apparatus will serve as a temporary substitute for a defective filter part?
27. What will happen if one tube of a full-wave rectifier circuit burns out or becomes weak?
28. What will happen if a filter coil is short-circuited? If a filter condenser is short circuited? If a filter condenser is open-circuited?

The Mercury Vapor Rectifier Tube, page 506

29. Explain in detail why a mercury-vapor tube is capable of rectifying greater amperage than a vacuum tube of the same size.

CHAPTER XXVI

POWER SUPPLY FOR SOUND SYSTEMS

Nearly all the constituent parts of a sound installation require the application of electrical power of some kind, though the requirements vary considerably. Direct current at several voltages is needed, and more than one voltage of alternating current.

It will be advisable, for several reasons, to consider both the power requirements, and the methods used to meet them, before examining the apparatus in which that power is to be used. One of those reasons lies in the fact that (as has already been explained) the study of amplifier drawings is greatly simplified if the built-in power system can be recognized for what it is, and thus eliminated from any possible confusion with the amplifying action proper.

Varieties of Power Needed

(1) The list below must be taken as only a rough outline.

Exciting Lamps: d. c. or a. c., but most often d. c. Usually 8 to 12 volts, 2 to 4 amperes.

Photoelectric Cells: d. c. only. Usually 90 or 135 volts and only a minute fraction of an ampere.

Microphones: (Sometimes none) d. c. when used. Most commonly 3 to 12 volts; less than ¼ ampere.

Drive Motors: a. c. where possible; line voltage, usually 110.

Amplifier "A": d. c. sometimes; a. c. usually. One to 10 volts; ¼ to 12 amperes.

Amplifier "B": d. c. always. Up to 1,000 volts; ¼ ampere. Occasionally still higher power.

Amplifier "C": d. c. always. Usually less than 50 volts; almost zero amperage.

Speakers: d. c. always. From 7 to 110 volts or higher: seldom more than 5 or less than 1/10 ampere.

The above list represents the actual, or primary requirements, of average sound systems. Since power lines do not furnish electricity in such variety means of adapting the power supply to sound purposes must be installed in the projection room. (2) Power converters are often built into speakers, amplifiers, etc., as integral parts of those units, in which case a speaker, for example, may seem to be a. c. operated.

Dry Cells

(3) One method of providing for some of these power needs is to use dry cells, which is often done wherever the amperage requirements are low enough to make it practical. Dry cells are quite commonly used to bias photo-electric cells; also occasionally for the "C" requirements of amplifiers. They may also be used for the "B" power of very small amplifiers.

Line D. C.

(4) Direct current from a commercial power line cannot be used for most d. c. power purposes. It is, for example, useful as a source of supply for speaker fields, but useless for photo-cell supply. The distinction is very simple. The photo-cell has amplification behind it; the speakers have not. Any sudden voltage changes, ripple or other unsteadiness in the power line would be amplified if that line were used to bias the photo-cell, and commercial d. c., being commutated a. c., always has some ripple. The same irregularity in the loud speaker supply does no harm since it does not undergo amplification. At worst, a condenser filter may be necessary to smooth the ripple a trifle, and to take out the clicks caused by abrupt changes in voltage.

(5) In general, line d. c. can be used for sound power only in such connections as do not subject its inherent irregularities to amplification. In practice, this confines its use almost wholly to speaker field circuits, with or

without the help of a filtering condenser, and often with the help of a rheostat to reduce the voltage to that required by the speaker, or by a number of speakers connected in series. The arc lamp d. c. supply from a rectifier or motor-generator can be, and sometimes is, used in the same way.

Motor Generators

One method of providing for the varied d. c. requirements listed above is to install a number of generators, which may be driven by either a. c. or d. c. motors, according to the power supply available.

(The fundamental principle of motor-generator action, and some details of motor-generator construction, will be found elsewhere in this volume. It does not seem advisable to go into further detail here. Books containing almost endless information about motors and generators can be found in any public library, or may be obtained from any publisher of technical books. No space that could be allotted here could do the subject equal justice. To attempt to include such details would only take that much space from matters peculiar to the projection craft, concerning which very little information is generally available.)

As used in the projection room for sound power purposes, motor-generators are usually small, light machines that can be switched on and off without necessity for any starting rheostat. (6) They are generally equipped with filters to eliminate commutator ripple. Filter, voltage regulating resistance, switches and fuses may be mounted in one "generator control cabinet" or may be distributed in several cabinets or boxes. In any case the connections represent only commonplace electrical circuits, and the projectionist should have little trouble in tracing and understanding those with which his own projection room is quipped.

Tracing Circuits

(7) It is always advisable to study an unknown circuit by means of a schematic, or skeleton drawing, which

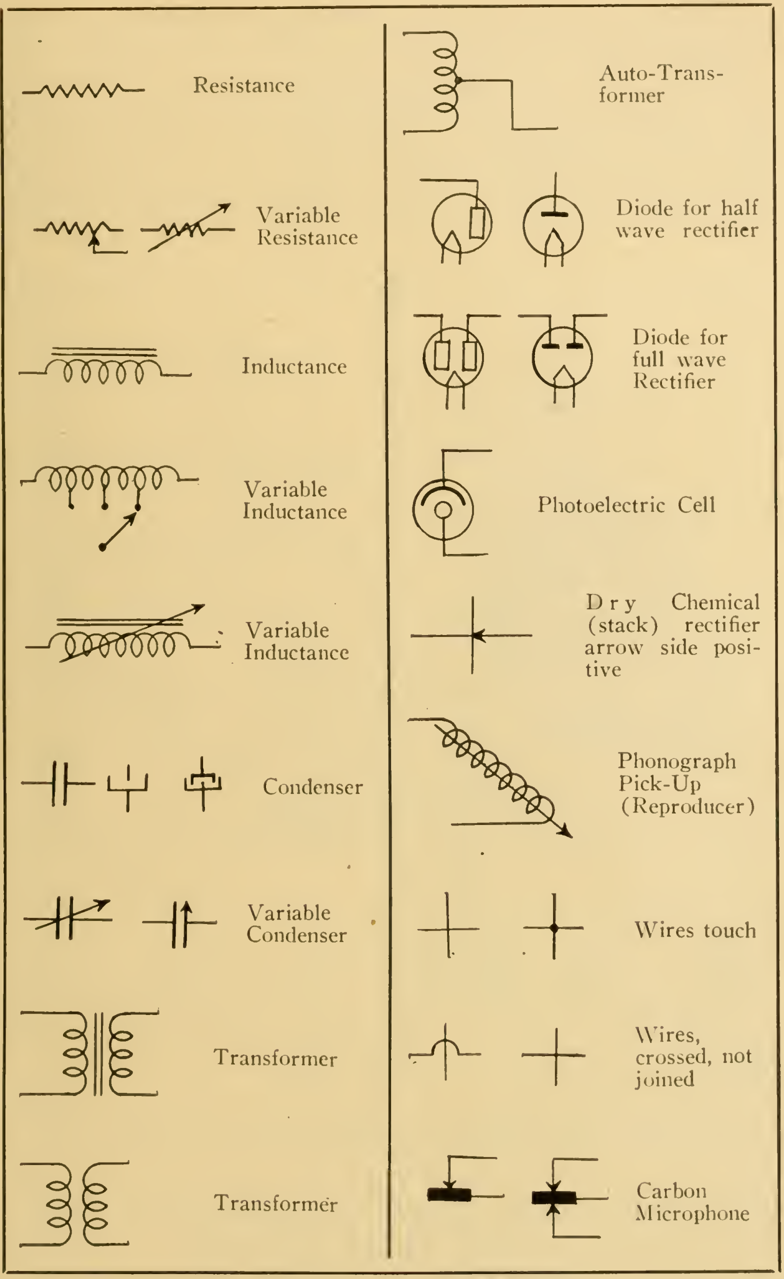


Fig. 111—Symbols Used in Electrical Drawings

the manufacturer of the apparatus should be very willing to supply.

Figure 112 is the wiring diagram of the control box for a sound supply motor generator. To the beginner it may seem complicated, and difficult to understand or trace. (8) But let us look at Figure 113, which is the schematic or skeleton drawing of the identical circuit.

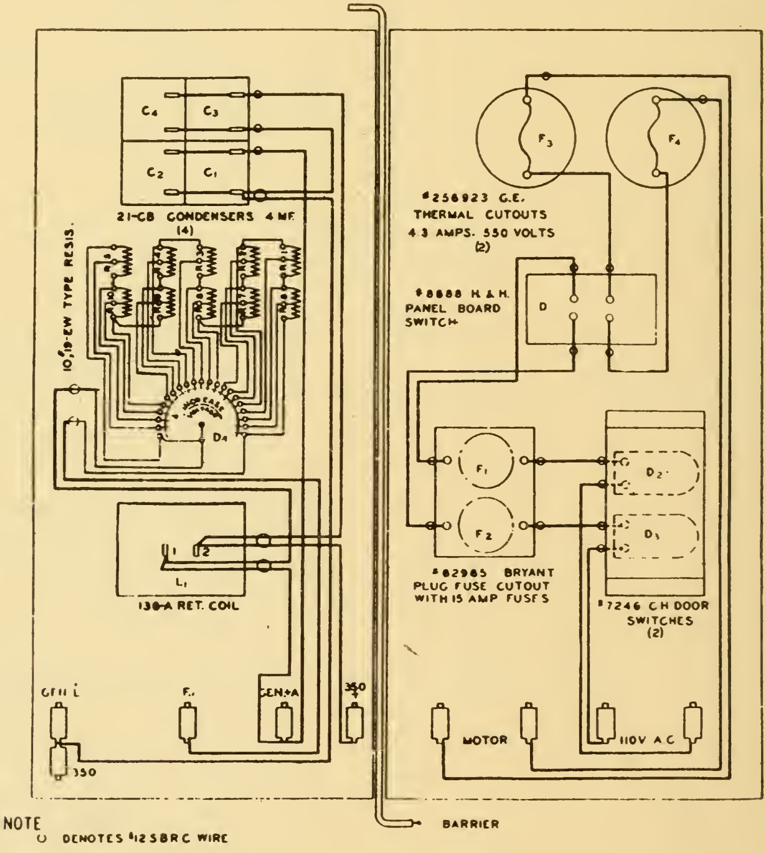


FIGURE 112.—Wiring diagram of control cabinet for sound supply motor-generator.

Figure 113 is about as simple and understandable as any such electrical arrangement can possibly be.

At its upper left hand corner are two terminals for the 110-volt a. c. wires that supply power to the motor of this motor-generator. Below are two switches so mounted on the cabinet door that they automatically break the power supply circuit when the cabinet is opened. This is a safety device. Below are two fuses; the control switch for starting the motor; two other fuses, or heat-operated cut-outs, and terminals for the wires leading from this cabinet to the motor.

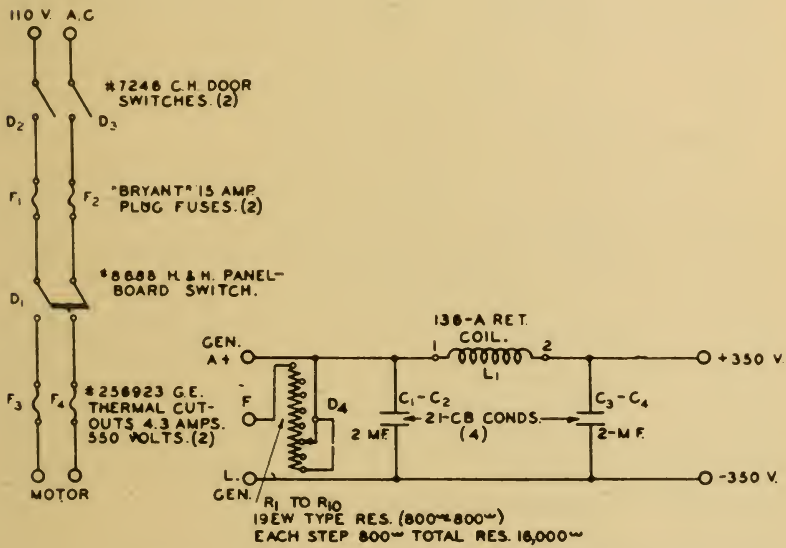


FIG. 113.—Schematic or simplified presentation of the circuits of Figure 112.

The second circuit shown is that of the generator. At the left are three terminals to which wires from the generator are connected. The central terminal, marked F, is wired to the generator field. Just to the right of this terminal is the generator field control (voltage regulating) rheostat, and to the right of this is the filter, consisting of retard coil L-1, and two sets of condensers (C-1, C-2, C-3 and C-4) in a conventional filter circuit. To the right of the filter are the two terminals through which the 350-volt direct current output is wired to the amplifier in which it is needed.

(9) In this drawing the electrical facts are arranged with respect to the convenience of the eye and mind

studying them. The electrical relationships of the different parts are shown as simply as the draftsman could draw them. But the actual physical apparatus must be arranged with respect to convenience in wiring and repair, and with regard to economy of space inside the cabinet that contains them.

Figure 112 shows the same equipment and wiring as Figure 113, drawn exactly as they are placed and wired in the physical cabinet. Every part shown in Figure 113 can be located in Figure 112 by reference to the part numbers. For example, the filter retard coil L-1 is shown at the lower left of Figure 112, just above the field rheostat terminal F.

Just above L-1, in Figure 112, is a complicated-seeming arrangement of resistors and a tap-switch, which would be troublesome to trace in detail if Figure 113 did not explain to us exactly what that resistance is, and precisely how it is wired into the circuit. It is, of course, D-4, the generator field control, or voltage regulator. There will never be the least occasion to trace its wiring in detail except in case of trouble within that resistor itself, or in its tap-switch contacts. Everything else the projectionist will ever need to know about it is most conveniently shown in Figure 113.

Storage Battery Charger

Another method of converting line power to direct current of suitable voltage is to use the commercially-supplied electricity to charge storage batteries. In a few systems, in the past, as much as 350 volts at low amperage was drawn from storage batteries for amplifier "B" supply. This practice never became widespread because of the inconvenience involved in cleaning and watering the large number of cells necessary. But storage batteries are quite commonly used for *low*-voltage d. c. since only a few cells are required.

(10) Where the line power is direct current, the charger is merely a rheostat that serves to reduce the line voltage to that necessary for charging. (11) A. c.,

however, cannot be used as charging current. It would first charge the battery and then discharge it, repeating this cycle of events 60 times a second (assuming the current to be 60-cycle). (12) Therefore a. c. must be converted to direct current if it is to be used as charging power.

(13) In comparatively rare cases an a. c. motor drives a d. c. generator which in turn charges the batteries, but the commonest form of a. c. charger makes use of a rectifying tube. A charger of that type is shown schemati-

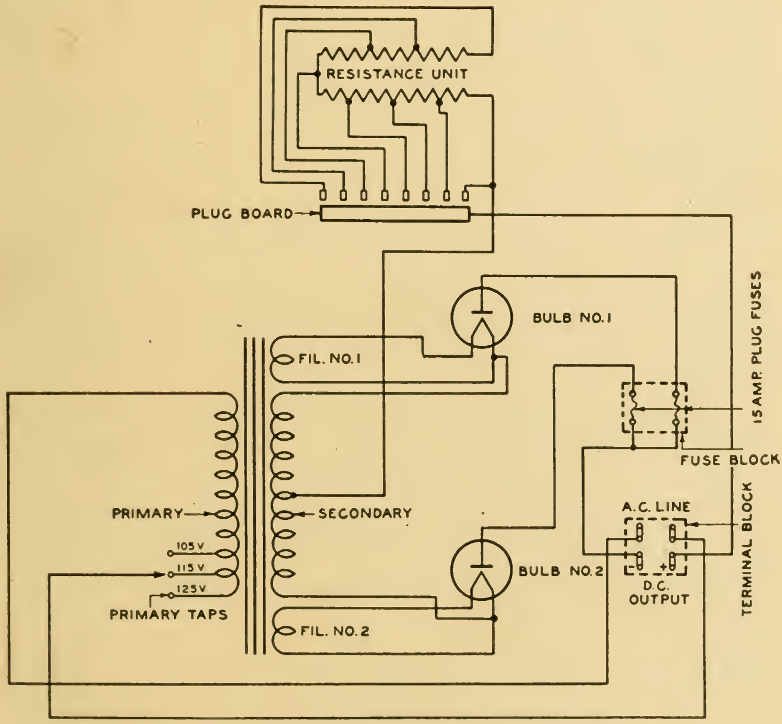


FIG. 114.—Type 40 G.E. Tungar Battery Charger.

cally in Figure 114. We are now prepared to trace its circuit in detail and to study the action of its tubes.

FILAMENT CIRCUITS OF FIGURE 114

(14) In the center of Figure 114 are two circles, each containing an inverted "V" with a horizontal line above

it. The circles represent the glass envelopes of rectifying tubes. The "V" 's are the filaments, which emit negatrons when heated.

It will simplify matters to forget all the rest of the charger for the moment, and see how those filaments are supplied with heating current.

At the lower right of the drawing is a terminal block to which an a. c. power line is wired through some external switch that will serve to turn the charger on and off. From the a. c. terminals of this block wires run around the bottom of the drawing to the primary winding of a transformer, which is equipped with three taps, arranged to accommodate voltages from 105 to 125, according to voltage of the power supply line.

A. c. from the line flows through this primary and completes its circuit back to its source and in so doing generates alternating voltages in the three secondaries of the transformer, as explained on Page 461. The top secondary, marked "Fil. No. 1," and the bottom secondary, marked "Fil. No. 2," are wired directly to the filaments of the two tubes, No. 1 and No. 2, and the current generated in those secondaries heats the filaments.

Now let us assume that those filaments are heated, and emitting negatrons, and forget about their secondaries, which serve no other purpose than to heat them. The rectifying action proper is concerned only with the middle secondary of the transformer, and with the horizontal lines (plates) drawn above the filaments of the two tubes.

Rectifying Tube and Its Circuits

(15) The type of rectifying tube shown in Figure 114 contains within its glass, but completely insulated from the filament, a plate of metal or carbon which is shown in the drawing by the horizontal line placed just above the filament of each tube.

(16) The plates of the rectifying tubes are in circuit with the middle, or plate secondary of the transformer. This secondary has a center-tap connection which divides

it into top half and bottom half. Each half serves the plate circuit of one rectifying tube.

Let us trace the top half and its circuit. Since the current generated in the secondary is alternating, the center-tap will alternately be positive and negative with respect to the ends. Tracing from the center-tap, the circuit runs right and upward to the resistance unit. One of the plugs connected with this unit will be plugged into the plug board. The drawing shows the circuit open at this point merely to indicate that any plug may be used, according to the amount of resistance required. From the end of the plug board the circuit runs right, then down, to the d. c. output terminal near the lower right-hand corner of the drawing and thence through the external load and in again at the other d. c. terminal. From there we trace it upward through the right-hand 15 ampere plug fuse to the plate of bulb No. 1. From the filament of that bulb a wire returns to the upper end of the plate secondary of the transformer.

Under normal operating conditions the resistance unit is plugged to the plug board, as has been explained, and there is an external load across the two d. c. terminals; therefore this circuit is complete except for the gap in the tube itself. Now the plate of the tube is connected, through the circuit as traced, to the mid-tap of the secondary of the transformer, and the filament of the tube to the upper end of that secondary. Whenever the mid-cap is positive with respect to the upper end of the secondary coil, the plate of bulb No. 1 must be positive with respect to its filament. (17) Whenever that happens negatrons emitted by the filament will be attracted to the positive plate, closing the circuit across the vacuum.

When the mid-tap of the secondary becomes more negative than the upper end of the secondary, the plate of bulb No. 1 will be negative with respect to the filament of bulb No. 1, and the negatrons will be repelled by the plate, thus opening the circuit. The emitted negatrons will linger in the vacuum, thereby constituting a space charge, and eventually return to the filament, which at that moment is positive.

(18) Hence bulb No. 1 acts as a switch that opens automatically every time its plate becomes negative, and closes automatically every time the plate becomes positive. This is the action of any rectifying tube.

Let us for a moment longer continue to forget bulb No. 2, and concentrate on bulb No. 1. The circuit we have just traced is a complete rectifying circuit. Assume that a storage battery in need of charging is connected across the d. c. terminals of this charger, and consider the result.

Whenever the mid-tap of the transformer secondary is positive with respect to the filament of bulb No. 1, negatrons, which always move toward positive from negative, flow out of the upper end of the secondary to the filament, across the vacuum to the plate, through the fuse and terminal into the negative plate of the battery. From the positive plate of the battery an equal number of negatrons flow through the positive terminal to the resistance unit, and so back to the secondary mid-tap. Thus negatrons are supplied to the negative plate of a storage battery and taken from its positive plate, and the battery, as explained on Page 447, undergoes the electro-chemical process called "charging."

When the polarity of the transformer secondary reverses itself an open switch appears in this charging circuit, namely, being bulb No. 1, through which the negatrons cannot flow through while the plate of that bulb is negative because a negative plate repels them.

(19) The above is a complete "half-wave" charging or rectifier circuit. It is called a half-wave circuit because charging current flows only half the time, that is, whenever the mid-tap of the secondary winding is positive with respect to the upper end of that secondary. Only half of the a. c. cycle, or wave, is used as charging power.

(20) Now, by tracing the wires, the reader can see for himself that the circuit of bulb No. 2 is exactly the same as the circuit of bulb No. 1, except that it is in reverse polarity. When the mid-tap of the secondary

is negative with respect to the upper end of the secondary it must of necessity be positive with respect to the lower end of that same winding. Therefore when the automatic vacuum-switch of bulb No. 1 is open that of bulb No. 2 is closed, and vice versa.

When the plate of bulb No. 1 is positive the plate of bulb No. 2 is negative, and vice versa. When current flows across the vacuum of bulb No. 2, none flows across the vacuum of bulb No. 1.

Thus, with both tubes in operation, the d. c. output is nearly continuous because the same instant current stops flowing across one vacuum it starts to flow across the other.

The complete circuit of Figure 114 is therefore a full-wave rectifier, consisting of two complete half-wave circuits so arranged that each rectifies one-half of the a. c. cycle.

Power Supply Rectifier

If the rectifier-type charger will deliver d. c. to charge a storage battery, which in turn provides d. c. to operate the sound system, why not use the charger itself to operate the sound system, and thus eliminate the battery?

In the past few years a great many theatre storage batteries have been eliminated by precisely this process.

However, the d. c. furnished by the charger cannot be used for sound purposes without filtering. The ripple in the rectified current would create hum in the sound. The (21) power supply rectifier is simply a full-wave battery charger with a "brute force" filter added.

(22) The schematic circuit of one such device is shown in Figure 115. It is an extremely simple circuit that the projectionist can trace without difficulty if he understands and remembers the battery charger circuit just considered, and the explanation of "brute force" filters given on Page 475.

Circuit of a Power Supply Rectifier

The upper portion of Figure 115 is an ordinary full-wave rectifier, identical except in minor details with the

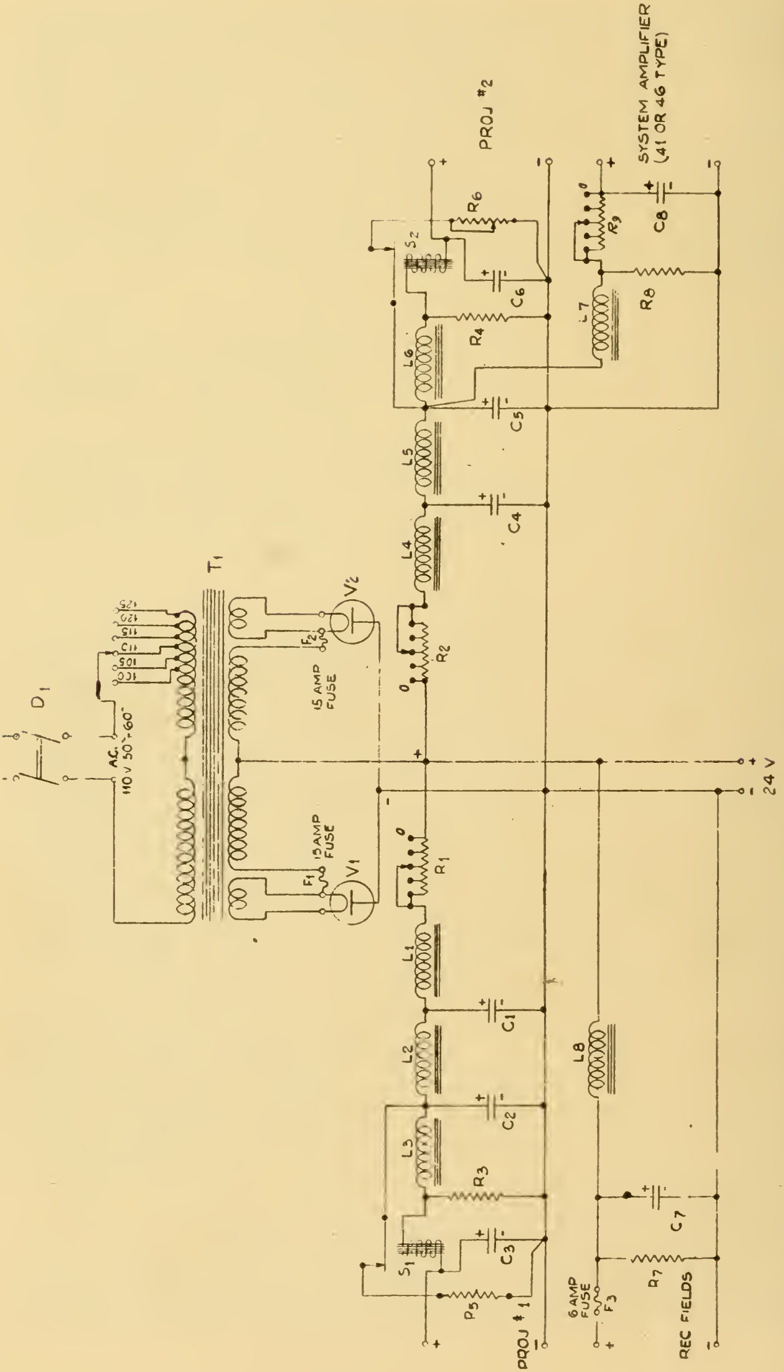


FIG. 115. Tube-rectifier power unit supplying low-voltage DC.

charger circuit of Figure 114. The transformer primary is adjustable between 110 and 125 volts. There are three secondaries, just as before. The rectifier tubes in this particular drawing are marked "V-1" and "V-2." The filaments are shown as inverted "U's" rather than as inverted "V"s. The plate secondary of the transformer is tapped at the center, as in the charger. The real difference between Figures 114 and 115 lies in the d. c. circuits, after rectification has taken place; instead of a simple pair of d. c. output terminals, which are to be wired to a storage battery, Figure 115 shows the d. c. line branching into five parallel circuits, four of which are equipped with "brute force" filters.

To study Figure 115, look first (bottom center of drawing) at the terminals marked "24 volts, + and —." The positive wire runs directly up to the mid-tap of the secondary; the negative wire runs to the plates of the two tubes. Current, moving from negative to positive, flows from the filament of either tube to the plate of that tube, through the wire marked —, through the external load, back in at the wire marked +, and thence to the mid-point of the secondary. Thus the plates, while always negative with respect to the mid-point of the secondary, are alternately positive and negative with respect to their own filaments, precisely as in the case of the charger.

Branching from these two output wires and running off to the left are two complete filter circuits. The upper one terminates in two binding posts marked "Proj. No. 1, + and —." This upper circuit filters and supplies d. c. for the exciting lamp and amplifier filaments of that projector. At the right-hand end of the filter is an adjustable rheostat, R-1, which may be set to secure the precise voltage desired. (23) From right to left, follow choke coils L-1, L-2 and L-3, and condensers C-1, C-2 and C-3, which constitute the filter itself. Resistor R-3, of 40 ohms, is a "bleeder" that helps R-1 reduce the 24-volt output of the rectifier to the 12 volts required by the projector.

To the left of L-3 is S-1, a protective relay. When projector No. 1 is turned off excessive current might flow in the other apparatus supplied by the rectifier if S-1, in co-operation with R-5, did not serve as protection. S-1 is in series with the supply line to projector No. 1. When that projector is operating S-1 acts as an electro-magnet, pulling the hinged bar just above it away from the arrowhead contact. When the circuit of projector No. 1 is opened, current no longer flows through S-1. The hinged bar springs back and makes contact with the arrowhead. The current supplied then flows through R-5, which thus serves as a substitute load whenever projector No. 1 presents an open circuit.

This arrangement protects other apparatus in case of an accidental open circuit in projector No. 1. It also permits that projector's exciting lamp and photo-cell amplifier to be turned off whenever not in use, thus lengthening the life of the lamp and of the amplifier's tubes.

Directly to the right of the filter-supply to projector No. 1 is a similar arrangement supplying the other projector. This last circuit, however, is slightly different. A line branches off from the second filter stage and runs through a third filter, which has its own voltage regulating rheostat and bleeder. This third filter, shown in the lower right hand corner of the drawing, supplies a quarter of an ampere to the filaments of the vacuum tubes in the board, or system, amplifier. It has no protective relay since the system amplifier is not turned off separately.

At the lower left of the drawing is still another output circuit, with only a single stage filter consisting of one inductance and one condenser. This supplies magnetizing current to the field windings of the loud speakers and (24) does not need much filtering because a. c. hum in this circuit will not be amplified.

The 24-volt d. c. terminals at the bottom of the drawing can be used, if desired, with or without an external filter, for still other d. c. purposes. For example, if properly filtered they could supply microphone power.

The circuit of Figure 115 is identical in principle to the rectifier circuits built into modern amplifiers to provide them with high-voltage "B" current.

Care of Tube Rectifiers

A rectifier such as that shown in Figures 115 and 116 requires very little attention. (25) The relay contacts of S-1 and S-2 should be burnished occasionally to insure that they make firm and solid connection.

Excessive heating of any part should of course be investigated immediately. Such over-heating may be caused by excessive current drain that must be corrected. It may be caused by a growing defect inside the coil or condenser in question, in which event a duplicate part must be procured at once. It may also be caused by a defective connection to the part, which should be re-soldered. The cause need not be at the point where the overheating occurs, but can be a defectively low resistance in any other portion of the same circuit.

(26) In the event of any coil or condenser of the filter system burning out, when no spare is available for immediate replacement, a satisfactory temporary repair can usually be effected by borrowing storage batteries from the nearest charging station and connecting them in parallel to the damaged circuit. A sufficient number of cells should be connected in series to make the voltage of the battery as a whole equal to the voltage of the d. c. line in question. A storage battery "floating" across a d. c. line constitutes one of the best of all filters for slight to medium ripple.

(27) The tubes of this type of rectifier require some attention. If either one burns out, that event will be indicated by a marked drop in the power supplied, as well as by a strong hum in the sound; the latter resulting from the fact that the unit is then operating on one tube only, as a half-wave rectifier, with a correspondingly heavier ripple which the filter is not designed to remove.

Hum will also be heard if one tube, through age or for any other reason, becomes much less efficient than its partner. In that case the good tube is carrying the greater part of the load, and the unit functions essentially as a half-wave rectifier. The defective tube must be replaced. In practice, two new tubes are installed, and the old ones tested by restoring them one at a time later on, when no audience is present.

(28) A short-circuited filter coil will cause hum; so will an open-circuited filter condenser. A short-circuited filter condenser will burn out the fuses F-1 and F-2, shown in Figure 115 alongside the tubes.

Mercury-Vapor Rectifier Tube

(29) A gas-filled tube is capable of rectifying heavier current than a vacuum tube of the same size. The gas commonly used for this purpose is mercury vapor. When the tube is cold drops of mercury can be seen clinging to the inner surface of the glass. The liquid metal vaporizes or boils when the filament is heated.

The action of the vapor is approximately as follows: negatrons from the heated filament "collide" with atoms of the gas, thus ionizing them. In greater detail, what happens is that occasionally one of the outermost negatrons of a mercury atom will find itself powerfully repelled by the field of an emitted negatron, which is approaching rapidly from the direction of the filament. Under some circumstances the repulsive force acting upon atomic negatron will be strong enough to drive it away from its atom. The remainder of the atom then constitutes a positive ion, while the detached negatron goes on to the positive plate precisely as if it had been emitted by the filament. Therefore at any given moment during its operation a mercurcy-vapor tube contains numbers of positive ions of mercury, which assist the emission from the filament, in the following manner:

It must be remembered (see Page 452) that an emitting cathode is surrounded by a space charge. When the cathode is in the same tube with a positive plate, some of the negatrons that make up the space charge are drawn to the plate. Some negatrons, however, are emitted with such feeble velocity that they never travel far enough from the cathode to respond to the attraction of the distant plate, but return to the cathode instead. Thus the

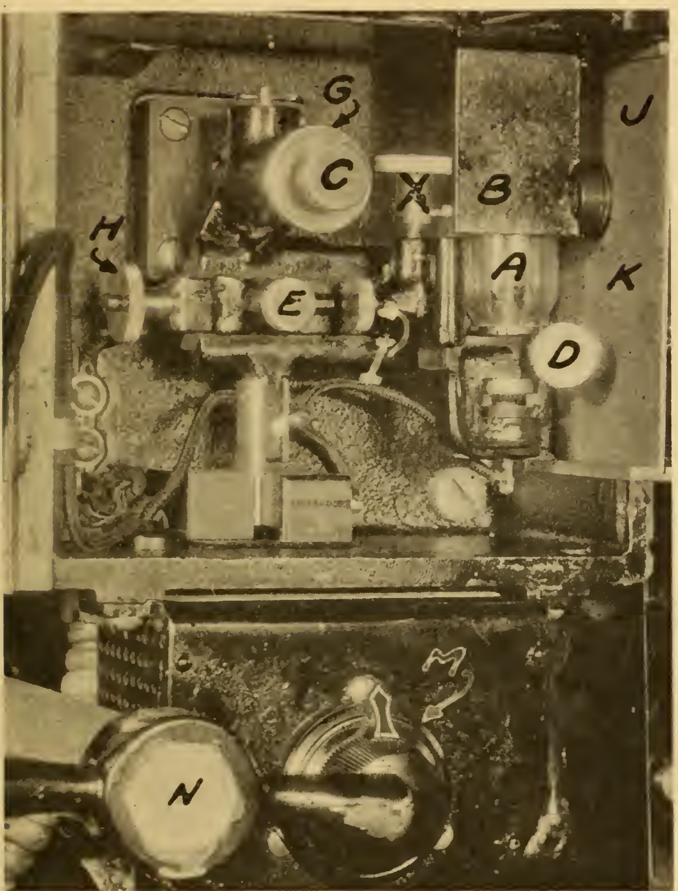


FIG. 116.—View of Exciting Lamp Compartment Electric Reproducer Set. A—Exciting lamp. B—Shield to protect projectionist's eyes from glare. D—Screw by means of which exciting lamp may be clamped into its socket. J and K—Partition between exciting lamp and sound gate compartments. It may be removed merely by pulling it out toward you. C and G—Thumbscrew enabling the moving of the lamp sidewise and clamping it into place when adjustment is finished. X—Thumbscrew by means of which exciting lamp may be raised or lowered vertically. When adjustment is completed it is clamped immovably by screw I. By means of thumbscrew H, the lamp may be moved forward or back for focusing the light upon the slit. This adjustment is clamped immovably by means of thumbscrew E. M, located under this compartment, is the dial by means of which current is adjusted to the proper value, as shown by the ammeter on the front of the compartment door. This current must be maintained exactly at the amount set in your instruction book. Any alteration in the current value would cause over or under illumination of the sound track and change the volume of sound. Be very careful about this matter. N is the handle by means of which the angle of projection may be altered when using the Western Electric universal projector base. The insulated wire runs to the ammeter on the compartment door. The sound gate compartment adjoins the exciting lamp compartment on its right.

filament of a rectifying tube is surrounded by a thin layer of negatrons. The presence of this layer, or space charge, exercises a repulsive force upon other negatrons that are just inside the surface of the filament, and would be emitted if this surrounding space charge did not repel them.

But the positive mercury ions are attracted toward the space charge, which of course is negative, and unite with the negatrons. The mercury ions then become neutral mercury atoms again until they are re-ionized by a new collision, and the space charge has been destroyed. Therefore the effect of mercury vapor in a rectifying tube is to make possible much greater emission than could possibly take place in a vacuum rectifier of the same size, with the result that a small mercury-vapor tube can, as before said, rectify as much current as a large vacuum tube.

"Dry Chemical Stack"–or "Disc"–Rectifiers

Tubes of either vacuum or mercury-vapor type can be omitted entirely, and the same work be performed by rectifying "stacks" or discs. Some circuit changes, however, would be needed if stacks were substituted for the tubes in Figure 115. The nature, operation and circuits of disc rectifiers are described on Page 287.

SOURCES OF SOUND CURRENT

1. From what three sources are sound currents obtained in the projection room?

Reproduction of Sound on Film, page 511

2. Explain the action of a "lens tube."
3. What is the purpose of the "sound gate"?
4. What does the photo-cell "see?"
5. How does the photo-cell "see" frequency?
6. What light-beam focus is necessary to reproduce 9,000 cycle sound? Why?
7. How does the photo-cell "see" volume?
8. How is volume recorded on a variable density sound track?
9. How is volume recorded on a variable area sound track?
10. Explain noiseless recording.
11. Does the use of noiseless recording require any changes in the projection room?
12. Describe the construction of a photo-electric cell.
13. What is the difference between the cathode of a photo-electric cell and the cathode of a rectifying tube?
14. Describe the cathode of a photo-electric cell.
15. Describe the anode of a photo-electric cell.
16. How and why does the photo-electric cell create sound currents?
17. Are all theatre photo-cells, photo-*electric* cells? What is a photo-conductive cell?
18. Describe and explain two methods of photo-cell coupling.
19. What is "condenser coupling"? "Transformer coupling"?

Care of Sound-on-Film Equipment, page 521

20. How is the exciting light focus adjusted?
21. Describe two practical methods of testing exciting light focus.
22. What harm is caused by oil in a lens tube?

23. What care does the sound gate require?
24. What is "flutter"? Name two causes of flutter.
25. What harm is done by mis-adjustment of lateral film guides?
26. State two methods of testing the adjustment of lateral film guides.
27. What harm is done by vibration of any part of the light system?
28. What test is applied to discover vibrating parts of the light system?
29. What test is used to discover noisy "B" batteries?

Production of Sound on Disc, page 525

30. Describe the magnetic disc reproducer, and its action.
31. What are "hill and dale" records?

Microphones, page 527

32. Describe the common carbon-type microphone, and its action.
33. Explain "packing" in the carbon microphone, its causes and cure.

Transmission Line, Pick-Up to Amplifier, page 529

34. Describe three methods of coupling the sound pick-up to the system amplifier.
35. Trace the circuits of a combination fader-changeover-volume control.
36. Describe a common method of connecting non-synchronous sound currents to the system amplifier.

CHAPTER XXVII

SOURCES OF SOUND CURRENT

(1) The alternating (or pulsating direct) current that represents sound in the projection room is obtained from one of three sources:

(a) The film reproducing system, which contains a photo-cell circuit.

(b) The disc or phonograph reproducer.

(c) The announcing microphone.

The Film Reproducing System

Figure 117 is an accurate diagram of the essentials of a film reproducing system. It shows the position of the photo-electric cell with relation to its light source and to the moving film upon which a sound record has been

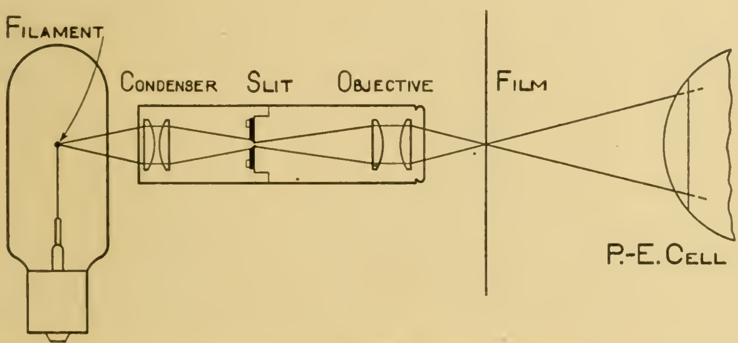


Figure 117

photographed. Figure 118 is a photograph showing the apparatus diagrammed in Figure 117. By studying these two illustrations the real simplicity of the film reproducing system will readily appear.

To the right of the lamp, in Figure 117, is an oblong case containing two sets of lenses, and a "slit." This is the "lens tube," "lens barrel," "slit assembly," "optical system"—all of which names are applied to this same piece of equipment by different manufacturers. It is shown in Figure 118 as a horizontal metal cylinder running from the exciter lamp shield to the sound gate.

To the left of the lens tube, in both pictures, is the exciting lamp. In Figure 118 the lamp is hidden behind its metal shield. (2) The action of the lens tube upon the exciting light is clearly diagrammed in Figure 117. The moving film appears in Figure 117 as a vertical line. In Figure 118 the film shows up white (blank leader was used to make the photograph). It is firmly clasped by the "sound gate" or "tension pad" at the point where it passes through the light coming from the lens tube. The photo-electric cell shown in the diagram cannot be seen in the picture. It is located in the photo-cell compartment just to the right of the sound gate.

(3) The sound gate holds the film in such fashion that it is free to slide downward. It is pulled downward, of course, by the sprocket that shows below and just to the left of the gate. But the pressure on the film as it passes through the gate is such that it cannot move in any other direction except downward. It cannot move forward or back out of the focal point, shown in Figure 117 as the place where the light rays from the slit assembly's objective lenses are focussed.

What the Photo-Cell Sees

(4) Assume that an opaque portion of the sound track cuts off the exciting light from the photo-cell, and is followed, a moment later, as the film moves downward, by a transparent portion. (See Figures 101 and 102). Assume that opaque and transparent portions of the sound track replace each other in the path of the exciting light a thousand times a second, as the film moves downward. In that case the photo-cell sees a light turned on and off a thousand times a second. A human eye would not see that. A human eye would be deceived by the phenomenon of "persistence of vision," which makes moving pictures possible, into seeing a steadily-burning light of

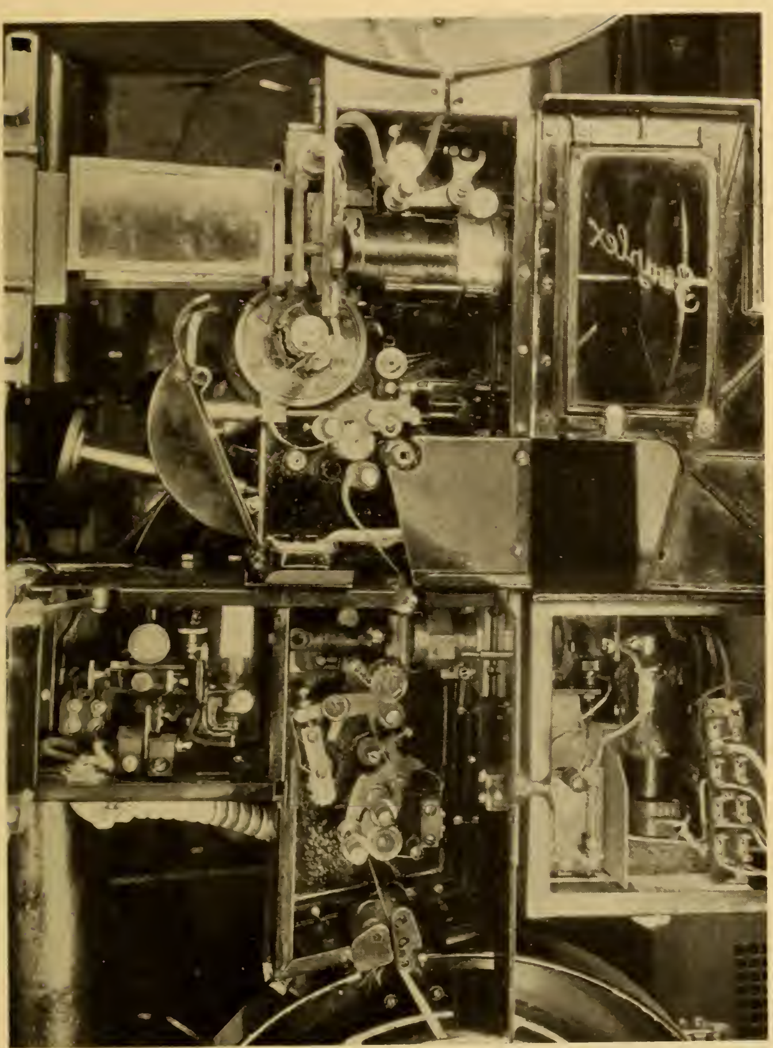


FIG. 118.—Projector head and sound "attachment" showing film threaded up. The sound attachment consists of the exciting lamp compartment at the left (compare Fig. 116) the drive or center compartment, and the photo-electric cell compartment, at the right. This last also contains the photo-electric cell amplifier.

medium intensity. But the photo-cell can see a light turned on and off any number of times a second. When it sees this happen, for example, a thousand times a second, it responds (for reasons made plain below) by creating a thousand-cycle pulsation in the direct current flowing through it. If the opaque and transparent portions of the sound track are more crowded, and succeed each other five thousand times a second, the photo-cell creates a 5,000-cycle ripple in its direct current.

How the Photo-Cell "Sees" Frequency

(5) Consider a high-pitched sound, say of 9,000 cycles (which is 18,000 alternations), photographed on a sound track. The photo-cell must see 9,000 transparent areas and 9,000 dark areas in one second's time if it is to create a 9,000-cycle pulsation in its direct current. The film moves downward at a uniform rate of 18 inches per second. Therefore if 18,000 different areas (9,000 light and 9,000 dark) are to pass through the sound gate in one second's time, each of these light and dark areas must occupy exactly one one-thousandth of an inch along the length of the film. (6) Now if the dark areas are to cut off the light completely, and the transparent areas are to transmit it completely, then the light beam itself must obviously be not more than one one-thousandth of an inch in height.

If 4,500-cycle sound were to be considered satisfactory as the upper limit of reproduction, then the light beam would need to be focussed to only 1/500th of an inch. But in every case the light must be brought down to some definitely narrow line at the point where it crosses the sound track. If this is not done at all, if a flood of light, say, an inch high, is permitted to pass through the film to the photo-cell, then it is plain that nothing higher than 18-cycle sound can be reproduced.

The function, therefore, of the slit assembly diagrammed in Figure 117 is to reduce the height of the beam of exciting light to the dimensions necessary for highest frequency of sound desired.

The exciting lamp, which co-operates in this work, is unusual in that its filament appears as straight, horizontal line of wire. The light from this straight line of incandescence passes through the condenser lenses of Figure

117 to the slit. The objective lens focusses an image of the slit upon the film.

How the Photo-Cell "Sees" Volume

(7) Let us consider two musical notes that are identical in frequency, but differ in volume. Then in each case the photo-cell will see the same number of changes of light per second. But there will be a more drastic change in the case of the louder note, in consequence of which the cell will create a stronger ripple in the direct current flowing through it. The explanation of this cell action will follow in a moment.

(8) Reference should first be made to Figures 101 and 102. These show that in the "variable density" type of sound track the dark areas are darker, and the light areas lighter, in some portions of the sound track than in others. Those parts of the track in which the contrast between light and dark is greatest are the parts in which loud sound has been recorded—that is, those parts in which the action of the light valve in the recording studio has been strongest. Those parts of the variable density track where the light valve moved very little, and the contrast between light and dark areas is not great, represent low volume.

(9) With a track of the "variable area" type (Figure 101) the amount of light reaching the photo-cell is varied by altering the areas of the light and dark portions of the track.

Noiseless Recording

(10) The earliest sound tracks were based on the principle of recording dark areas on an otherwise transparent track. The result was that during times of low volume or no sound at all light passed through the film to the photo-cell, and caused a noise called the photo-cell "hiss." The grain of the film also created "ground noise."

(11) Noiseless recording involved no apparatus changes in the projection room, but modifications in the studio that kept the sound track practically dark when there was no sound, and illuminated it only in proportion to the

extent of the volume recorded. Hence the hiss and ground noise is always much less in volume than the sound at any given moment, and therefore inaudible.

CONSTRUCTION OF PHOTO-ELECTRIC CELL

(12) The principle of construction in the photo-cell is very similar to that followed in the rectifying tube. In each case there is a cathode and an anode. (13) The difference is that the cathode of the photo-cell is not a filament serving as an emitter when it is heated, but a light-sensitive metal serving as an emitter when it is illuminated. When light is shut off emission ceases. The response is instantaneous. When light is admitted to the cathode the emission varies in strength in proportion to the amount of light received.

(14) Because it operates by light rather than heat, the cathode of the photo-cell is not a thin filament wire, but a broad surface constructed to intercept nearly all the light that enters the cell. It takes the form of a film or layer of the active metal deposited, in earlier types, on the inside of the glass of the cell, and in later types on a curved element provided for that purpose. (15) The anode or "plate" of the photo-cell is not a plate at all, but a thin bar or thin ring of metal that will shadow the cathode as little as possible.

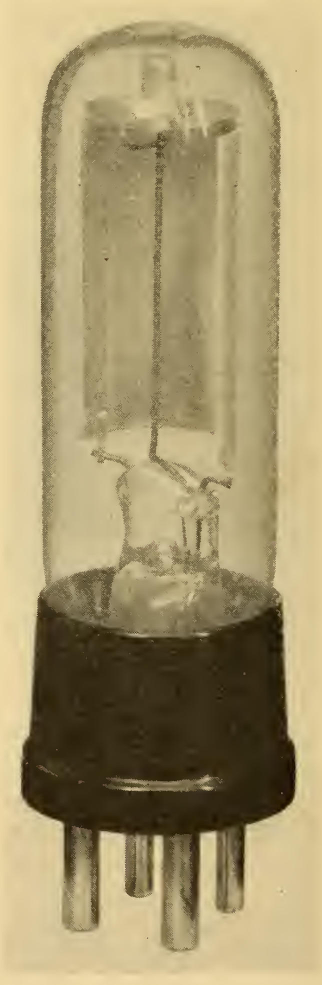


FIG. 119.—A modern type photo-electric cell.

The two elements of the photo-cell are connected across a source of extremely steady, ripple-less direct current, drawn either from a dry battery or from an exceptionally well-filtered rectifier supply. One such circuit is shown in Figure 120. (16) Negatrons emitted by the cathode when light strikes it are attracted to the positive anode. This action constitutes a flow of current across the cell. Because the emission depends entirely upon the light reaching the cathode, the cell acts as a highly sensitive valve, permitting current to flow through it (anode voltage being constant) in proportion to the amount of light to which it is exposed. Since the response of the cathode is substantially instantaneous, the cell finds no difficulty in dealing with light fluctuations that correspond to even the highest frequencies of audible sound.

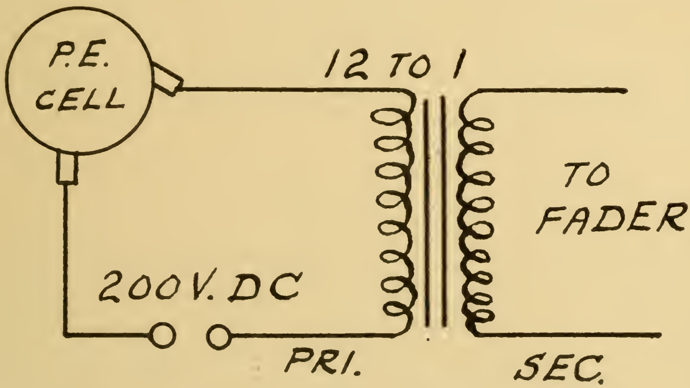


Fig. 120.—Photo-cell coupling. (Transformer coupling).

The arrangement of Figure 120 results in a flow of pulsating direct current through the primary winding of the 12-to-1 ratio transformer. The amperage flowing (the micro-amperage, to be more exact) will fluctuate in strength as many times per second as the light entering the cell changes, and will be proportionate in its strength to the strength of that light.

Thus the opaque and transparent areas of the sound track are converted, through the motion of the film and the operation of the photo-electric cell, into corresponding pulsations of direct current.

Varieties of Photo-Cells

Most modern photo-electric cells are gas-filled because the presence of gas increases the emission of such cells in precisely the same way that gas increases the emission of a rectifier tube filament. (See Page 508.) The gas used in photo-cells, however, is not mercury vapor, but one of the rare gases, usually argon.

(17) Photo-conductive, as distinct from photo-electric, cells are used in a few sound systems. They consist merely of small pieces of the metal selenium, suitably mounted in a convenient holder. This metal has the property of acting as insulator in the dark and as a conductor when illuminated. It is believed that light causes an internal emission of negatrons from its atoms, while in darkness these negatrons cling to their atoms and repel any free negatrons attempting to flow through the metal as part of a current. (See Page 432.) A strip of this metal can readily be substituted for the cell shown in Figure 120, with simple circuit modifications for retaining impedance match.

Photo-Electric Cell Coupling

(18) Figure 120 shows one common method of "coupling"—that is, wiring—the photo-electric cell to the switches, volume controls and amplifiers in which the pulsations of its direct current are controlled and amplified. In Figure 120 that current merely flows through the primary of a step-down transformer. The result is a flow of alternating current in the secondary winding that reproduces all the fluctuations of the pulsating direct current in the primary. But the voltage and amperage are altered. The voltage is reduced to 1/12th, and the amperage multiplied nearly 12 times. The sound current drawn from secondary of the transformer in Figure 120 passes through a fader before entering the system amplifier. The fader is essentially a double-throw, double-pole switch that connects the system amplifier with sound current from either projector. In some systems the fader serves as a volume control as well as a

changeover. In such cases it is not built in the form of a switch, but of a double potentiometer, as explained on Page 530.

A second method of photo-cell coupling is shown in Figure 121. This method is used in connection with an amplifier mounted on or near the projector, and connected to the photo-cell by a very short wire. It deserves exceptionally careful study because the identical circuit is also used in amplifiers for "coupling," or wiring together, amplifying tubes.

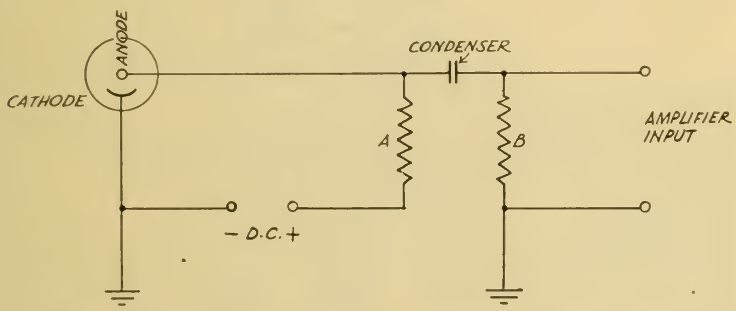


FIG. 121.—Photo-cell coupling. (Condenser-resistance coupling).

In Figure 121 negatrons from the d. c. source travel to the cathode of the cell, are emitted under the influence of light, and cross the cell to the anode. Thence they move through Resistor A to the positive side of the d. c. source, thereby completing their circuit.

But a parallel circuit can be traced from the d. c. negative terminal through the common ground, thence upward through Resistor B, then through the condenser and downward through Resistor A to the positive d. c. terminal. Since this circuit contains a condenser in series with it, it cannot carry smooth d. c. but only the ripple, or a. c. component, created by the photo-cell action. (See Page 467.) This ripple or a. c. component is precisely the part that corresponds to the sound to be reproduced, and by the circuit of Figure 121 it has now been transferred to Resistor B, which looks into the amplifier. The alternating voltage drop across Resistor B is wired directly to the input terminals of the amplifier.

(19) This arrangement is condenser-resistor coupling. The arrangement of Figure 120 is called trans-

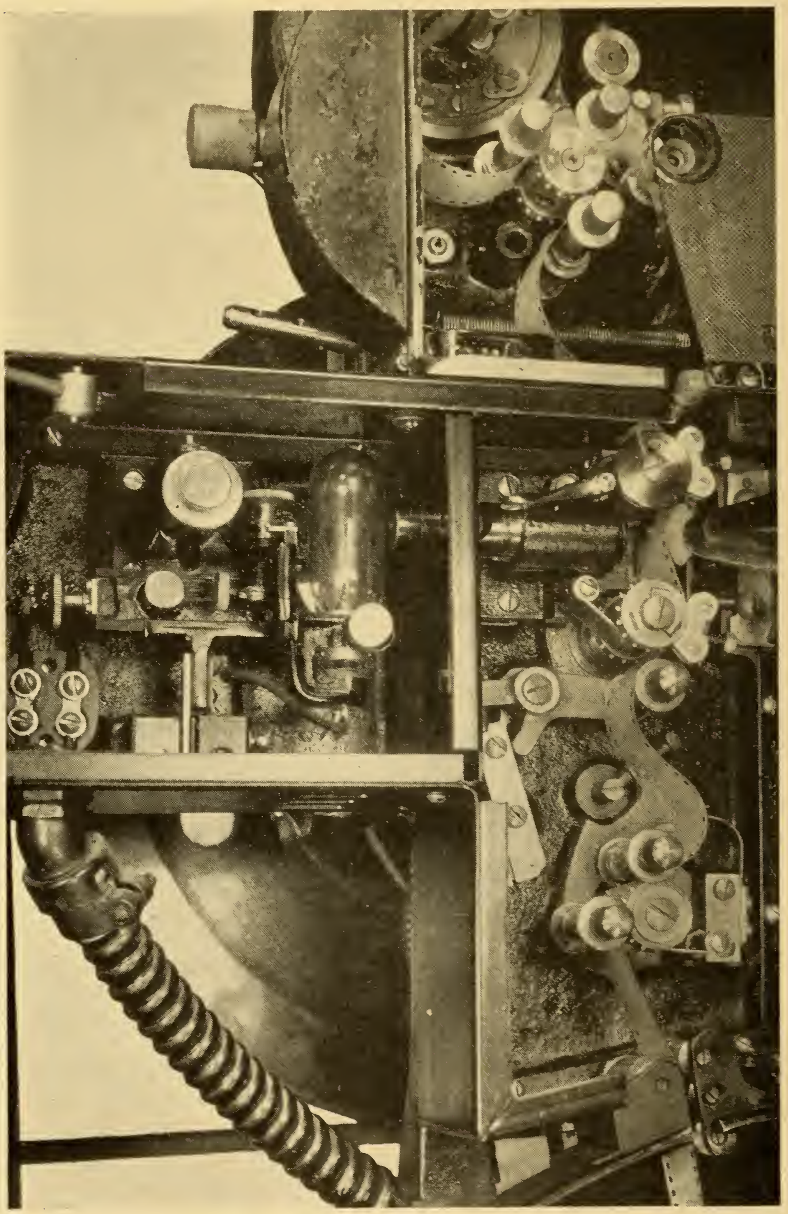


FIG. 122.—Western Electric "Wide Range" Soundhead.

former coupling. Either may be used in connection with photo-electric cells, or between the tubes of amplifiers.

Figure 122 is a clear picture of a film reproducing system, which it is suggested that the reader study by way of review. The exciting lamp is shown without its light shield. The thumb-screws below and to the left of the lamp are the means by which the light beam is focussed to secure minimum height at the point of the sound-track. The photo-electric cell is not in the picture but is located in the compartment to the right of the sound gate. The film used for this photograph is blank leader (chosen because it will show up white), having neither pictures nor sound track.

Figure 123 shows a sound-head in which the beam of the exciting light is bent upward by the "Photo-cell condenser lens." The photo-cell, in other words, is not located in a straight line with the lens tube, as in Figure 117, but a bit above it. The light beam is bent upward after it has passed through the sound track.

Care of the Film Reproducing System

Everything about the film reproducing system is delicate, and requires extreme care. The focus of the exciting lamp is a matter of a fraction of a thousandth of an inch. The current of the photo-electric cell is a matter of a millionth of an ampere. And the slightest defect or irregularity in this part of the apparatus is subject to the full amplifying power of the sound system.

(20) The focus of the exciting lamp must be accurate. In the normal course of operation correct focus is not secured by adjusting the lenses or the slit, but by careful placing of the exciting lamp, the mounting of which can be moved until focus is obtained and then locked in place by set-screws. (21) A rough test for focus is to hold a white card in front of the photo-cell and adjust the focus until a clear white oval is obtained. A more accurate test is to run a loop of high-frequency test film, six or nine thousand cycles, while an output meter is con-

nected in the loud speaker circuit. The output meter reads sound volume in decibels (the decibel is a unit for

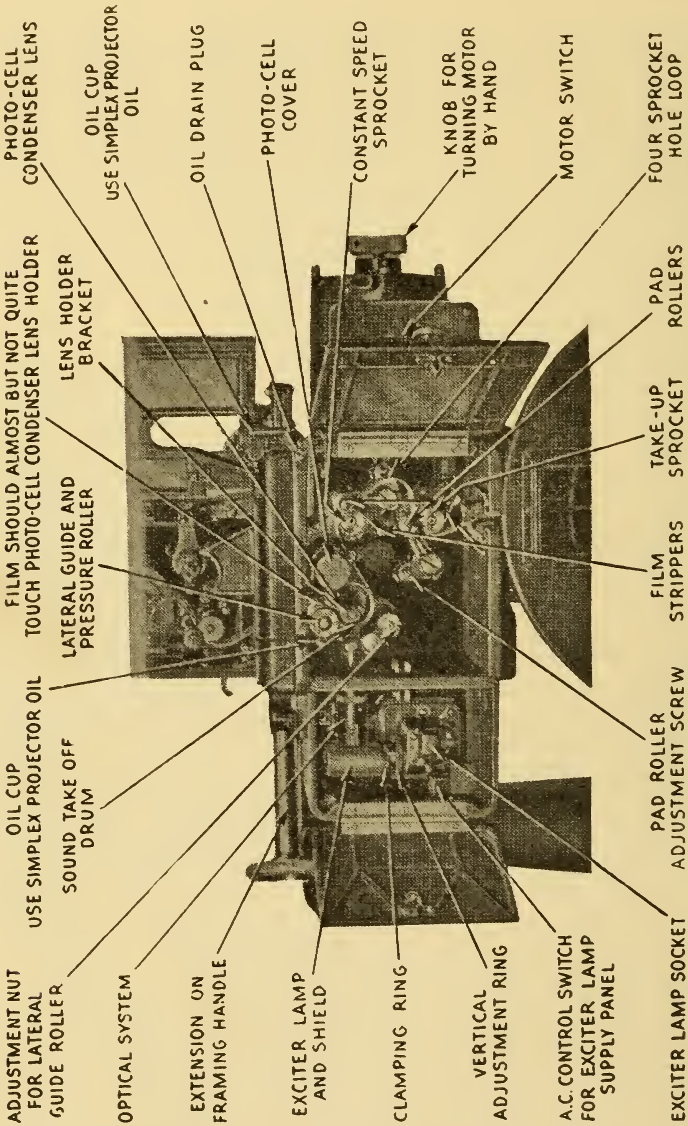


FIG. 123.—RCA Photophone Soundhead with Rotary Stabilizer.

measuring volume as the ampere is a unit for measuring current). The exciting lamp mounting is then adjusted until the maximum volume is shown by the registration of the meter.

The lenses of the slit assembly must be kept clean and free from oil. The outer lenses are cleaned with tissue paper, preferably lens tissue. In some makes of equipment the lens tube can be opened, cleaned and adjusted in the projection room, but other manufacturers seal their lens assemblies to prevent this practice. Some types of assembly can be focussed in the projection room, while in others the focus is fixed and the exciting lamp controls are the only means of modifying the focus.

(22) Oil should be kept away from the lens tube. It seeps inside, vaporizes under the heat of the exciting lamp, and turns the light yellow. The photo-electric cell does not respond well to yellow light. Loss of volume, especially at high frequencies, is experienced when the exciting light is dimmed in this way, and the only remedy is either to open and clean the lens assembly (if it can be opened in the projection room) or to return the assembly to the factory for overhauling.

(23) The sound gate, or tension pad, must be kept scrupulously clean. Particles of dirt or lint or film wax caught in the gate may vibrate with the motion of the film and add an unintended interruption to the light. This will result in noisy sound.

(24) The motion of the film past the sound gate must be utterly smooth. The slightest jerk will result in "flutter," which is a tremolo in the sound, and very unpleasant. The same result will follow if the sound gate does not hold the film tightly, but permits it to move forward and back through the point of focus. The motion of the film is controlled by the sprockets and idlers, which are described on another page under the heading of "Drives."

The "lateral guides" control the film on its downward course to insure that the entire sound track, and nothing but the sound track, passes through the exciting light.

(25) There are sprocket holes in the film on one side of the sound track, and dividing lines between the pictures on the other side. If the film is laterally displaced so that

either pass through the light beam, the light will be interrupted at the frequency with which sprocket holes (or dividing lines, as the case may be) pass through the point of focus. A loud hum or "motor-boating" in the sound will result. (26) This can be cured by adjusting the lateral guides until it is no longer heard. An observer in the theatre is necessary if the adjustment is to be made with the greatest accuracy, since a slight trace of such noise will not be heard by the projectionist above the noise of his machinery, although loud enough to annoy the audience.

The most perfect adjustment of the lateral guides is secured by placing a piece of blank leader in the projector and photographing the exciting light upon it. An exposure of from 30 seconds to one minute will leave a thin black line on the blank film. The drive should then be turned to move the film about six inches, and another exposure made. Four or five such exposures will reveal very accurately whether the film is out of adjustment laterally with respect to the exciting light. After the guides have been re-set the light must be photographed again, and so on, until a perfect setting is obtained and the guides are locked into place.

(27) It is necessary to guard against the slightest vibration of any part of the light system. If the slit in the lens tube vibrates, or the filament of the exciting lamp vibrates, the resulting vibration of the light beam will be heard in the sound as noise. (28) The exciting lamp and its holder should be tested for vibration by tapping them gently with the back of lead pencil, one that has no eraser. The lens tube should be rapped more vigorously with the same instrument, or tapped very gently with the butt of a screw-driver. The photo-electric cell and its amplifying tubes, if any, should be tapped softly with the side of a pencil. Any noise heard in the sound as a result of these tests means that the part in question is subject to vibration and must be tightened accordingly, or replaced.

The current supply to the photo-electric cell must be faultlessly smooth d. c. (29) If it is drawn from dry batteries, high resistance test phones should be connected directly across the battery terminals. If any noise is heard in the phones the battery has become too noisy for use with a photo-cell, and must be replaced.

The Disc Reproducer

(30) The phonograph pick-up, or reproducer, is a miniature generator in which the physical motion that generates current is reciprocating, rather than rotary as in the case of a power-supply generator. The needle tracking the groove of the record vibrates from side to side at the same frequency with which irregularities of the groove follow each other. The distance through which the needle vibrates varies according to whether the irregularities of the groove are large or small.

Attached to the needle, inside the reproducer, is a small piece of iron. Lines of magnetic force originating in a steel magnet within the reproducer flow through this piece of iron and also through a coil of wire. When the needle vibrates, the piece of iron attached to the needle holder vibrates with it, and the strength of the magnetic field, as it passes through the coil of wire, is varied accordingly. This change in magnetic strength generates an alternating current in the wire. The frequency of this current corresponds to the frequency of the needle's vibration, and its strength to the distance through which the needle moves.

Some of the highest grade pick-ups contain oil as a "damping" medium. The needle-holder assembly is generally resonant at some frequency of audible sound, and will therefore tend to vibrate more strongly at that frequency than at any other. The oil counteracts this tendency, but makes projection room repair of the pick-up distinctly difficult. It is not easy to replace the oil even if the right oil is at hand, and for that reason it is good practice to return such pick-ups to the factory even for simple repairs, rather than open them in the theatre.

The disc reproducer needs comparatively little attention, but the record and its turntable, and the reproducer mounting, or tone-arm, are almost as delicate in their requirements as the photo-electric cell equipment. Both turntable and tone-arm must be perfectly level, or the needle is likely to leave one groove and jump (fall downward) into another. A spirit level is used to check them from time to time. The record must turn smoothly, without any jerkiness in its motion, or flutter will result.

The needle point must be sharp enough to track through those slight variations of the groove that represent the highest frequencies of sound engraved on the record.

"Crystal" type pick-ups have come into the market very recently. They do not contain a magnet and a coil of wire, but a thin crystal of rochelle salts. A crystal of that salt will, for reasons unknown, generate current when it is subjected to a twisting motion. The needle and needle-holders are arranged to impart such a motion to the crystal in response to the irregularities in the groove of a moving record.

(31) "Hill and dale" records are those in which the groove is cut deeper and shallower, instead of wavering from side to side. In the common, or lateral-cut records, the spacing between grooves limits the amount of wavering possible, and therefore the volume. There is no such limit in the hill and dale. Hill and dale reproducers of course differ in construction from lateral-cut reproducers, in that the needle vibration must be up-and-down instead of from side to side.

Sound-on-disc can be drawn from any phonograph equipped with an electrical reproducer for exit marches or incidental music. A few years ago sound-on-disc records were furnished with film by the exchanges. These records were played on a turntable driven through an extension shaft by the same motor that operated the projector, hence were in synchronism with the picture. That method of securing synchronized sound is now obsolete in theatre work, but the old synchronous turntables are still used for incidental music in a few houses.

MICROPHONES

(32) The common, or carbon-type, microphone consists of a carefully weighed quantity of carbon granules between two metal plates, one of which is a diaphragm free to vibrate in response to sound vibrations in the neighboring air. The effect of the vibration is to vary the pressure on the carbon and thereby change its resistance to the flow of current. A steady direct current passes through the microphone. When the diaphragm vibrates the amperage increases and decreases in rhythm with the frequency of the sound that causes the vibration, and in proportion to its intensity. The commonest microphone circuit is that for the "double-button mike," shown in Figure 124. The granules in one "button" are compressed while those in the other are released from pressure. The resulting fluctuations in the current through the transformer primary generate an alternating current of corresponding frequency and strength in the secondary.

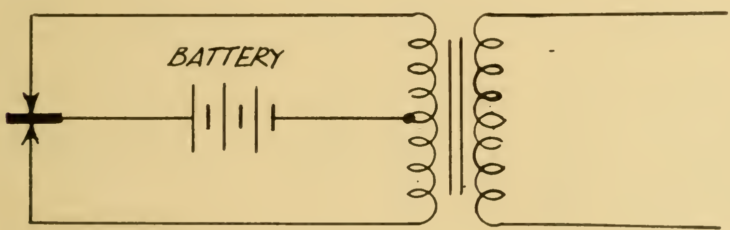


FIG. 124.—Circuit of a double-button carbon microphone.

(33) The carbon granules of this microphone may "pack" or cling together as a result of rough handling or of age. In that case they will not respond to vibration of the diaphragm. Gentle shaking will sometimes cure this condition. In severe cases it is incurable in the theatre.

Packing can be detected by reading the current through both buttons with a milliammeter, and this test should be applied from time to time as a precaution. Both buttons should have the same resistance, and if there is a marked difference in the meter readings the granules in one of the buttons are probably packed.

Excessive current through a carbon microphone will pack and ruin it. Minute sparking between the carbon granules will weld them together so firmly that only new carbon will restore the instrument.

Condenser and dynamic microphones are sometimes used in the larger theatres. The former is simply a condenser, one plate of which is constructed as a diaphragm. When that plate vibrates, changing the distance between itself and the other plate, the condenser undergoes a vibratory change in its capacitance, which is to say, in the quantity of charge it is capable of holding. A minute charge-discharge current flows in and out of the condenser through the wires that connect its plates with a d. c. source. This current is quite as weak as photoelectric cell current. Therefore condenser microphones operate with a small amplifier mounted inside the same casing.

The dynamic microphone is made in several forms, but essentially it consists of a metal diaphragm (or metal diaphragm carrying a coil of wire) that vibrates in a magnetic field. In other words, it is based on the same principle of construction and operation as the disc reproducer. Exactly as in the case of the disc reproducer, alternating current is generated by virtue of motion in a magnetic field.

Various forms of the dynamic microphone have come into increasing favor for theatre work, such as reinforcing vaudeville, "crooning" by the organist, etc. An interesting and popular variation is the "ribbon" or "velocity" mike, which consists of a very thin duralumin ribbon so mounted that it is free to vibrate in the field of a steel magnet. Sound waves approaching the edge of the ribbon exert equal pressure against both its faces and hence do not cause it to vibrate. This microphone is highly "directional," responding only to sounds that originate in the areas in front of it or behind it, and remaining "dead" to sounds that have their source at either side, or directly above or below.

"Crystal" microphones, similar in principle and construction to the crystal-type disc reproducer, are also used for theatre purposes.

Microphone pickup in a theatre may be amplified by the sound amplifier, but in some cases a separate amplifier is provided backstage for this purpose. For reinforcing vaudeville it is common practice to conceal a second set of speakers in organ grilles or above the proscenium arch, the sound speakers being "flown" or moved aside to leave stage room. The vaudeville speakers may be supplied with sound by the projection room amplifier, a changeover switch connecting them in place of the sound speakers. Use of a second amplifier located backstage is not a necessity.

At the present time microphones and disc reproducers are installed in only a small minority of theatres, and even in those are for the most part seldom used. Most theatre sound is drawn from a photo-cell.

Transmission Line: Pick-up to Amplifier

(34) There are almost as many methods of coupling sound pick-up to the system amplifier as there are types of sound equipment.

The simplest method is by use of a short cable from each photo-cell to the system amplifier. These cables run to a double-throw switch inside the amplifier casing. That switch serves as a fader, selecting sound from either projector, as desired. Volume is controlled by a potentiometer in one of the amplifier circuits. See Page

When the photo-cell coupling system of Figure 120 is used, the length of wire between the transformer shown in that diagram and the system amplifier is of no importance. A fader or changeover may be built into the amplifier for use with this method of coupling, or may be mounted in a separate cabinet, the output leads from which are then wired to the amplifier. The volume control is a potentiometer in one of the amplifier circuits.

When the sound system includes a small photo-cell amplifier mounted on or near the projector (see Figure 118) the output from that amplifier to the main amplifier often runs through a fader that is built as a double potentiometer and therefore serves as a volume control also. One device of that kind is diagrammed in Figure 125.

(35) Figure 125 represents one of a number of essentially similar devices created to serve simultaneously as volume control and as changeover. The projectionist who takes the trouble to follow the circuits of this simple diagram should have no trouble tracing out the wiring of any of its cousins.

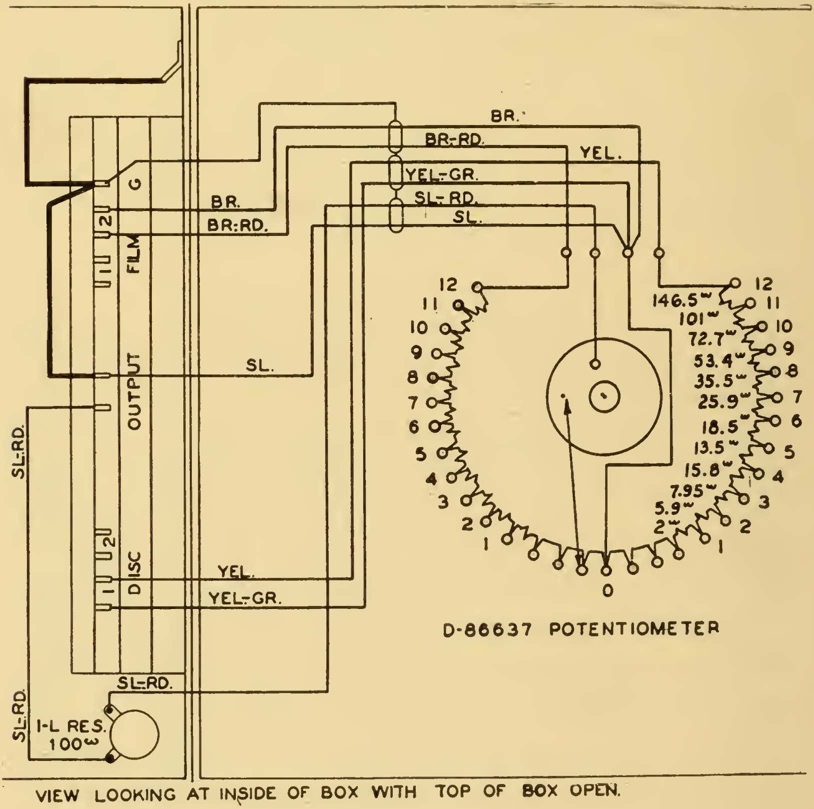


FIGURE 125

Along the left-hand side of Figure 125 are eleven terminal contacts, drawn as small rectangles. The top terminal is labelled "G" and connects to the grounded casing. The four terminals immediately below "G" are marked "Film 1 and 2." The output leads from the film reproducing system of each projector are wired to these two sets of terminals. About an inch below these are two terminals marked "Output." Through these this change-over device connects with the main amplifier. Below these, again, are two pairs of terminals for the synchronous disc input.

Let us return to the top left of this drawing, to the film input from No. 2 projector. The upper wire of this pair is brown and may be traced to Point O of the potentiometer. The lower wire, brown-red, runs to point 12 of the left-hand side of the potentiometer. Thus the entire resistance of the potentiometer is connected in parallel across the input from film reproducing system No. 2. Sound current coming from No. 2 projector, originating in its photocell, completes its circuit through the left-hand half of this potentiometer, and a corresponding alternating voltage drop exists across that resistance.

Now, looking at the two output terminals, we find that the upper peg, connected to the slate wire, also makes contact with Point O of the potentiometer, while the lower output terminal runs through the slate-red wire to the rotating element of the potentiometer, and its sliding contact. By means of this sliding contact (indicated by the double arrowhead which in the drawing connects the rotating element with Point O) any desired percentage of the voltage drop across the left-hand side of the potentiometer may be connected with the output terminals, and hence with the system amplifier. Volume from No. 2 projector is controlled by turning the central knob and thus changing the position of the sliding contact.

To change over, all that is necessary is to swing the central knob so that the sliding contact operates on the right-hand side of the potentiometer. Doing so disconnects the upper Output terminal from Projector No. 2, and places it in contact with Projector No. 1. The wiring from Film Terminals No. 1 to the right-hand side of the potentiometer is omitted from the drawing because it is an unnecessary complication. This wiring is identical with that connecting the left-hand side of the potentiometer to Terminal No. 2. Upper Terminal No. 1 runs to Point O; lower Terminal No. 1 runs to Point 12 of the right-hand half of the potentiometer.

The reader may care to trace out the Disc input connections of this circuit. No. 1 disc input wiring is shown; No. 2 disc input wiring is obviously the identical circuit applied to the opposite side of the potentiometer.

A number of control cabinet circuits similar to this one are equipped with supplementary key switches that do not alter the essential simplicity of the device, but add to the time required to trace out the drawings. One such switch may remove the potentiometer from the circuit entirely and substitute a resistance equal to that of a medium setting. This is for emergency, in case of trouble with the potentiometer resistors. Another such key is often provided to allow for the use of three projectors. This key is so wired that either No. 1 input or No. 2 input, as desired, may be used to take care of No. 3 projector. None of these circuits can be understood at a glance, but none of them will present any particular difficulty to any projectionist who is willing to take ten or fifteen minutes to trace their wiring step by step. Such analysis should, obviously, be made by every projectionist long before trouble occurs and compels him to attempt it under the pressure of an emergency.

Switching and Non-Synchronous Sound

(36) Such control cabinets as that shown in Figure 125 are not normally used with non-synchronous sound. In theatres that use announcing microphones or non-synchronous phonographs the output of Figure 125 would run to a small switching panel mounted with or near the main amplifier, not to that amplifier direct. By means of that switching panel the amplifier system can be connected either with the source of synchronous sound (the output of Figure 125) or with the non-sync source, as desired. The wiring of such switching panels is in the same class with that of Figure 125, in that it contains

nothing but simple electrical circuits, very easy to trace by anyone who is willing to give the job just a little time and patience. These circuits, also, should always be studied long before trouble appears.

THEORY AND WIRING OF AMPLIFIERS

The Amplifying Tube, page 536

1. Describe the construction of a 3-element vacuum tube.
2. How does it differ in construction from the rectifying tube?
3. What is the "space current" of an amplifying tube?
4. What is the "plate current" of an amplifying tube?
5. What is amplification?

Amplification and Its Fundamental Circuits, page 538

6. How is amplification secured in the 3-element tube?
7. Draw a simple amplifying circuit. Explain its action in de-detail.
8. What is inter-tube coupling? Describe the two common types.
9. What are some of the commoner methods of coupling used in amplifiers?
10. What is a push-pull amplification?
11. Why is it used?
12. Draw a simple push-pull circuit. Explain its action.
13. What is "inter-electrode capacitance"?
14. What is "feed back"?
15. What is "oscillation"?
16. How can amplifying power per stage be increased?
17. Describe the construction and purpose of a 4-element, or screen grid, tube.
18. Describe the construction and purpose of a 5-element tube, or pentode.
19. Explain "triode" and "tetrode."
20. Distinguish between Class A and Classs B amplification.
21. Explain Class AB amplification.

Amplifier Power Supplies, page 549

22. What is required of plate voltage supply for amplifiers?
23. Name and describe four methods of providing plate voltage for amplifiers.
24. What is required of filament power supply for amplifiers?
25. Name and describe methods of providing filament power for amplifiers.
26. What is required of the grid voltage supply for amplifiers?
27. Explain three methods of providing amplifier grid voltage.

Care and Troubles of Amplifiers, page 568

28. Name three items of care required by amplifiers.
29. Explain three ways in which a tube can be "bad."
30. Give two causes of bad contacts in amplifiers.
31. What two kinds of trouble are caused by imperfect contacts?
32. What three kinds of trouble are caused by overheating in amplifiers?
33. What three conditions might cause hum in amplifiers?
34. What trouble might cause feed-back in an amplifier?
35. How can loss of sound in an amplifier be traced to its cause?
36. How are other common amplifier troubles traced?

CHAPTER XXVIII

THEORY AND WIRING OF AMPLIFIERS

Tubes are the heart of every amplifier, and their construction and operation must be understood before the circuits of amplifiers can have any meaning.

Constructing a 3-Element Vacuum Tube

(1) The three-element amplifying tube consists partly of a cathode and an anode placed in a vacuum, and to that extent is in no way different from the rectifier tubes described on Page 498. (2) The amplifier tube can be thought of most conveniently as a rectifier tube with one element added, namely, the grid, or, more accurately the control grid (since there are also four- and five-element amplifying tubes that contain additional grids of no importance to the present discussion). Such additional grids are explained on Page 546. The commonest type of amplifying tube contains only cathode, anode and control grid. The control grid is placed between the cathode and the anode. Negatrons emitted

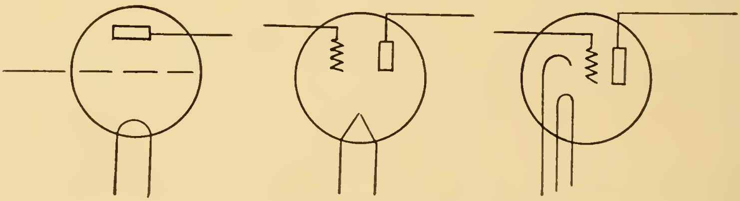


Fig. 126.—Three-electrode tube or triode.

by the cathode, and moving toward the anode, must pass through the control grid to reach their objective. That is the essential point about the tube's construction.

The Cathode of the Amplifier Tube

Cathodes in amplifier tubes are of two general types, direct and indirect heaters. The direct heater may be lit by either d. c. or a. c., since its temperature cannot change quickly enough to fluctuate with the a. c. cycle, and its emission will not vary at line frequency. If it is small, and quick to heat and cool, the cathode must be heated by d. c. Otherwise its emission will fluctuate at the line frequency (25, 50 or 60 cycles) and a corresponding hum will be heard in the sound. Indirect heaters have already been explained. (Page 452.) They make it possible to heat the cathodes of small tubes with a. c., without corresponding variation in emission. In such tubes the heating circuit and the cathode circuit are electrically insulated from each other.

Anode of the Amplifier Tube

The anode of an amplifier tube is commonly a flattened ring of metal, but in large tubes it is sometimes made of graphite or carbon. The choice of these latter materials arises from a desire to keep the ~~cathode~~ ANODE as cool as possible. In large-size theatre tubes, metal anodes become heated, sometimes to the point of glowing red or even white-hot, because they are subjected to incessant bombardment of negatrons emitted from the cathode. But an incandescent anode is in itself an emitter, like any other incandescent metal. And while negations emitted from the anode are drawn back into it again by its powerful positive charge and do not take any direct part in the tube action, the cloud of negatrons that have left its surface and not yet returned to it constitutes a space charge surrounding the anode which tends to repel negatrons approaching from the cathode. Carbon or graphite anodes, being thick and massy, are not easily heated to the point of incandescence. A graphite-anode tube is therefore capable of somewhat greater current flow from cathode to anode (and hence of greater volume without distortion) than a metal-anode tube of the same size. There are other advantages, however, in favor of metal-plate tubes. Both types are widely used at the present day, but the latter are more common.

Grid of the Amplifier Tube

Placed between anode and cathode, the grid consists of a metal skeleton or mesh with plenty of empty space between the turns of the spiral. It may be a ladder-like construction of metal, with empty space between the wire "rungs." It may be a loosely-woven fabric of metal screen, or "cloth." Occasionally it consists of a metal plate in which many holes have been drilled. The object of its construction is to compel negatrons moving through the tube from cathode to anode to pass close to the metal of the grid, without, however, interposing any physical barrier in their path.

"Space Current" of an Amplifying Tube

(3) The flow of negatrons from cathode to anode, across the empty vacuum of the tube, is called the "space current," (4) or plate current. If there were nothing else in the tube but the anode and cathode (no grid) the size of the plate current in milliamperes would depend wholly upon the emission from the cathode and the positive attraction of the anode.

(5) Amplification as obtained in a vacuum tube is the process of using a weak variable grid voltage to cause strong variations in the plate current. The tube, in short, is a valve, operated by a weak current and controlling a strong one. This has been said before. It cannot be repeated too often. When once that much about a tube is thoroughly understood it ceases to be any kind of mystery and becomes a very simple piece of electrical apparatus, with circuits that behave like any of the ordinary electrical circuits with which everyone is familiar.

How the Tube Amplifies

(6) Consider first the plate circuit. It has two wires, like any other circuit. One of these wires connects to the cathode of the tube, one to the anode. The positive wire goes to the anode. When the cathode is heated negatrons flow across the tube from cathode to anode, closing the

circuit. The strength of the current depends on the number of emitted negatrons that reach the anode, and hence upon the voltage across the tube and upon the strength of the emission.

Next, consider the grid circuit. It has two wires, like any other. One wire goes to the cathode, one to the grid. Cathode and grid are a small condenser; that is, two conductors separated by the insulation of the vacuum. The grid is kept always negative with respect to the cathode (how this is done is explained on Page 552), hence, negatrons cannot contact the grid and short-circuit the grid-cathode capacitance.

The grid circuit consists of two wires, its "load" is a tiny condenser; its source of power is the only unusual

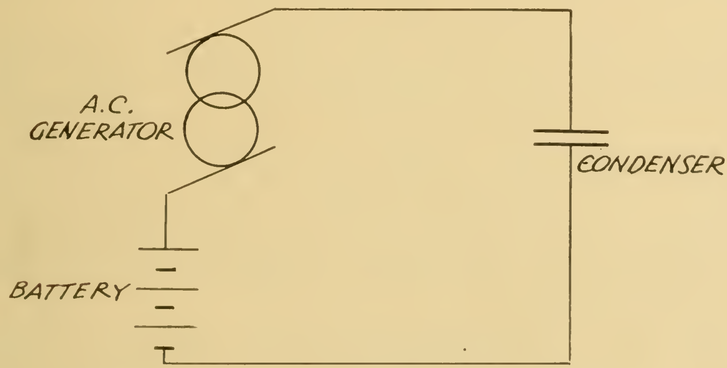


FIG. 127.—The electrical equivalent of a grid circuit.

thing about it. There are two sources of power, connected in series. One is the source of sound current to be amplified. This may be the secondary of a transformer, as in Figure 128. The other is plain d. c., wired negative to grid and positive to cathode, and called the grid (or "C") bias; it keeps the condenser always charged with cathode positive and grid negative, while the sound source in series varies the strength of that charge as its own strength and frequency change. The essential electrical characteristics are diagrammed in Figure 127.

These two circuits, grid circuit and plate circuit, are then simple electrical arrangements with nothing mysterious about them. The grid circuit arrangements are unusual, but not puzzling. The valve action of the tube depends upon the fact that the plate current (the flow of negatrons from cathode to anode) is extremely sensitive to the degree of negative charge upon the grid.

The reason for this sensitivity lies in the construction of the tube, which is so made that negatrons moving from cathode to anode must pass close to the metal of the grid. They do not touch that metal since the negative charge repels them, deflecting them sufficiently to cause them to pass through the empty spaces provided for that purpose. But if the negative charge is high many negatrons that would otherwise reach the plate do not pass through the grid at all. They are repelled when they come close to the grid and driven back again to cathode. If the charge on the grid were made sufficiently high the plate current would be zero, but it is not made that high. The grid bias is set at a very critical balance, so that a negatron approaching the grid is attracted by the distant positive plate, and repelled by the negative grid just ahead, with almost equal force. Under these circumstances a very small change in the grid charge makes a vast difference in the number of negatrons that are able to reach the anode.

Possibly an illustration will help make these simple facts even clearer, and prevent their ever being forgotten. Let us imagine a pair of very delicate, carefully balanced scales, with ten ounces in each pan. A one-ounce weight is then added to one of the two pans, and the other immediately rises. Ten ounces have been lifted by one ounce because the one-ounce weight upset a critical balance.

It is the same inside an amplifying tube. Whenever a few additional negatrons are added to the charge of the grid, a great many negatrons are prevented from reaching the plate, and repelled toward the cathode. Whenever a few negatrons are taken from the charge of the grid, a large number of negatrons that would otherwise have been repelled toward cathode are able to pass through the spaces of the grid and add themselves to the plate current. Every slight fluctuation in the charge of the grid is instantaneously duplicated in a corresponding but much greater change in the amperage of the plate current. A ripple, or a. c. component, is superimposed upon the plate current, that matches exactly every fluctuation of the speech-grid voltage that created it. The plate current ripple so produced is an amplified duplicate of the grid ripple.

That is the whole "secret" of amplification.

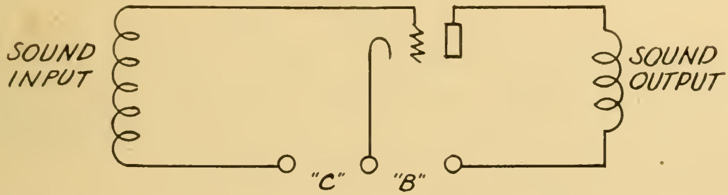


FIG. 128.—The arrangement shown here is the foundation of all amplifier circuits, regardless of how complex their details may be. The valve action of the tube permits the input circuit voltage to control the output circuit current.

(7) Figure 128 shows a simple amplifying arrangement with the plate and grid circuits described above. The filament-heating, or "A" circuit, which has no part in the amplifying action, is omitted from this drawing.

Both of the circuits shown in Figure 128 carry fluctuating d. c., which may be regarded (Page 474) as pure d. c. to which an a. c. component has been added. This latter is actually the case in the grid circuit, pure d. c. being supplied through the "C" terminals at the bottom of the drawing, and a. c. added by the transformer secondary marked "Sound Input." The a. c. component of the plate circuit is, of course, the ripple in the plate current created within the tube by the fluctuation of the grid charge. In Figure 128 both of these a. c. components must complete their circuit through the sources of d. c. supply (the terminals of which are marked "B" and "C"). But loss of volume and other disadvantages (see Page 577) arise from the practice of compelling sound a. c. to complete its circuit through the resistance of the d. c. power sources. Those disadvantages are avoided by the arrangement of Figure 129, which provides "by-pass" condensers to short-circuit the a. c. components around the d. c. sources. The condensers are of such

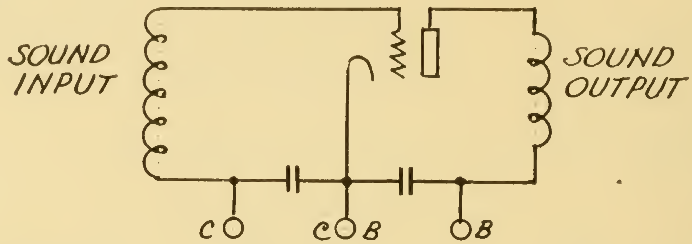


FIG. 129.—Showing the use of by-pass condensers.

size that they offer comparatively small impedance to the a. c. currents involved. The arrangement of Figure 129 is used in practically all modern amplifiers.

INTER-TUBE COUPLING

(8) No tube now available is so sensitive that photo-electric cell power applied to its grid will impart enough fluctuation to its plate current to operate a theatre-size loud-speaker. But the process that takes place in Figure 129 can easily be repeated by using the plate ripple in that drawing to modify the grid bias of another and more powerful tube. All that is necessary is to make the coil shown in Figure 129's plate circuit the primary of a "coupling" transformer, and then repeat the circuit of Figure 129 exactly. (9) This is done in Figure 130,

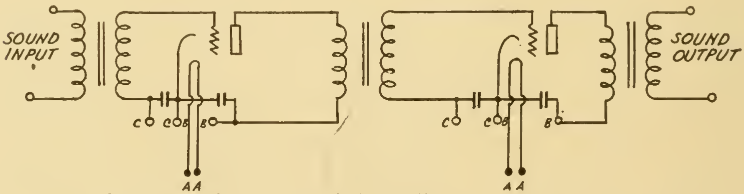


FIG. 130.—Transformer-coupled amplifier. (Compare Fig. 120).

which is a drawing of a "transformer-coupled" two-stage amplifier. Figure 131 illustrates "resistance coupling" between amplifying tubes. We have studied both arrangements in connection with the coupling of photo-electric cells to their amplifiers (see Figures 120 and 121), and there is no need of rehearsing the electrical

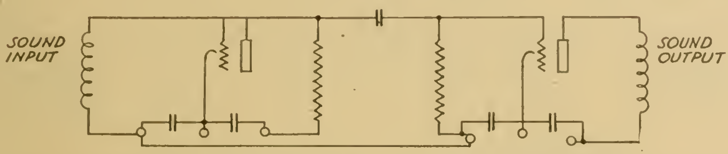


FIG. 131.—Condenser-resistor-coupled amplifier. (Compare Fig. 121). This circuit, as well as Figures 128, 129 and 130, has series plate feed. Compare Fig. 132.

action in this place. Both methods of coupling are commonly used in theatre amplifiers, usually with some modification.

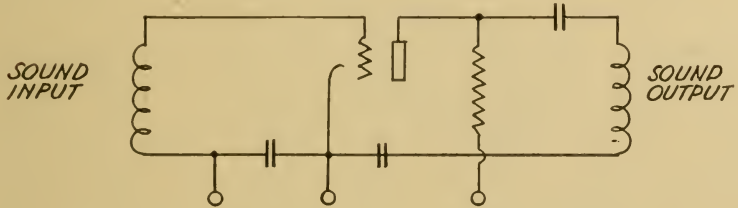


FIG. 132.—One-stage amplifier with parallel plate feed.

Transformer coupling is often accompanied by "parallel plate feed," an arrangement shown in Figure 132. This differs from Figure 129 only in that the d. c. component is kept out of the transformer, permitting the use of a transformer that is smaller, less expensive and more efficient. Figure 133 duplicates Figure 131 except that the grid resistor of the second tube has been made variable, and hence serves as a volume control. When the variable contact in Figure 133 is placed at the top of the resistor the arrangement duplicates Figure 131 exactly. When the variable contact is moved downward less than the full a. c. voltage drop developed across the resistor is applied across the grid and cathode of the second tube. Hence changes in grid voltage are smaller, the plate current across that tube varies less, and the volume drawn from the amplifier is lowered. This is the commonest method of controlling amplifier volume.

The volume-control resistor of Figure 133 is usually built in a circle or a semi-circle, rather than as a straight

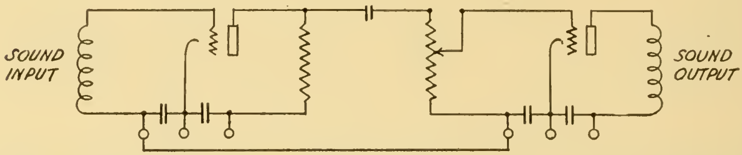


FIG. 133.—Illustrating use of coupling resistor for volume control.

line, and the adjustable contact is set by turning a knob, not by sliding it up and down as that drawing indicates. One manufacturer uses a motor to turn the knob, thus making remote control of volume a practical procedure. The motor can be operated from any point of the projection room where a suitable switch is installed, or from the auditorium. Mounted on the same shaft is a separate set of contacts (insulated entirely from the amplifier circuits) that operate a group of signal lamps. These lamps act as volume indicators, advertising to what point the sliding contact of Figure 133 has been set. Such motor-operated volume control is the exception. In most amplifiers the slider is adjusted manually. In some there is no slider, but only a switch that gives choice of either of two positions along the resistor, low volume and high volume. Sometimes there is a switch of that kind between tubes 1 and 2, and a sliding contact as in Figure 133 between tubes 2 and 3, or vice versa.

Push-Pull Amplification

(10) Figure 134 represents a very common variation of Figure 128, in which two tubes are used in the same stage of amplification. (11) This arrangement offers some improvement in both volume and quality (giving somewhat more than twice the volume of a single tube) and is especially favored in the later, or power, stages of an amplifier. The grid bias (12) of Figure 134 is shared by both grids, but when speech a. c. is induced in the secondary of the input transformer the upper grid will grow more negative while the lower grid becomes less

negative, and vice versa. In consequence the plate current of the upper tube will decline while that of the lower tube increases, with corresponding reciprocity in the two halves of the plate transformer primary. This push-pull or see-saw arrangement is used in almost all theatre amplifiers. It is a very simple modification of the circuit of Figure 128.

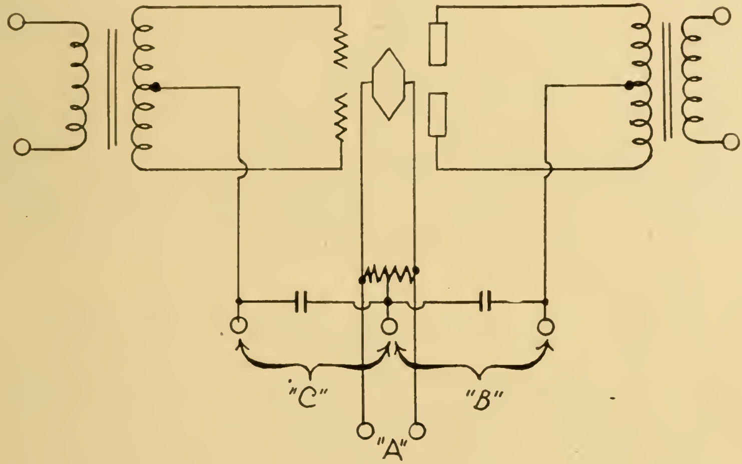


FIG. 134.—Fundamental circuit for push-pull amplification.

INTER-ELECTRODE CAPACITANCE

(13) We have noted before that the grid and cathode of a tube constitute two plates of a condenser, since they are insulated by vacuum and negatrons do not strike the grid. The same is true of the plate and the grid. They are conductors, they face each other, they are insulated from each other—hence they constitute a condenser, and capacitance exists between them.

"Feed-back" may take place as a result of this capacitance. (14) Feed-back is the name given to the condition where changes in plate voltage, resulting ultimately from changes in grid voltage, are "fed back" to the grid by the grid-plate capacitance. Inter-electrode capacitance, and therefore feed-back, exists in all three-element tubes, but does no serious harm unless an attempt is made to secure excessive amplification. When that is done the three-element tube will distort sound by amplifying some frequencies more strongly than others. If the amplification, and therefore the feed-back, is pushed still further the tube will "howl" at the frequency it has amplified most strongly, and nothing will come from the speakers but a continuous whistle. (15) The tube is in a condition of "oscillation," that is, acting as a converter that uses its d. c. plate power supply to generate an alternating current of audible frequency. It is no longer acting as an amplifier, but as an oscillator.

A good theatre amplifier is designed with sufficient "loss" to make sure that the maximum volume control setting cannot possibly cause any tube to oscillate, or even to distort sound seriously, although some theatre amplifiers of excellent manufacture do distort slightly at extreme high volume.

Increasing Amplification—Screen Grid Tubes

(16) To obtain more amplification per stage without distortion, and thus use fewer tubes, the design of the tube is modified to include a fourth element. This fourth element is the so-called "screen grid," and tubes containing it are "screen grid tubes."

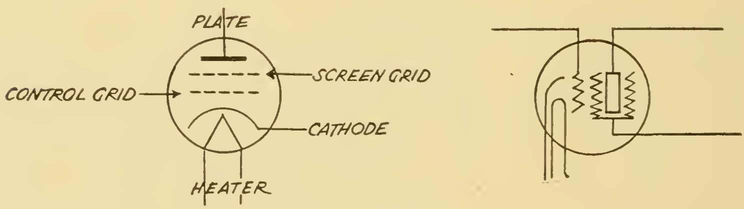


Fig. 135.—Screen-grid four electrode tube, or tetrode.

(17) The screen grid completely surrounds the plate. When this element is built into the tube there is no longer any effective inter-electrode capacitance between control grid and plate. The inter-electrode capacitances are between control grid and screen grid, and between screen grid and plate. The screen grid is maintained at a positive voltage that is slightly lower than the plate voltage.

Five-Element Tubes

(18) Although the amplification of a tube can be increased by addition of a screen grid, even this improvement does not enable the tube to work at its maximum capacity. There still remains another limiting factor which is called "secondary emission." This is the emission of negatrons from the plate, caused partly by the direct impact of negatrons coming from the cathode, and partly by the fact that the plate is heated by the multitude of such impacts. The presence of a positively charged screen grid close to the plate encourages such emission. The "plate space charge," that is to say, the cloud of negatrons that surrounds an emitting plate, repels negatrons coming from the cathode and limits the "space current" across the vacuum.

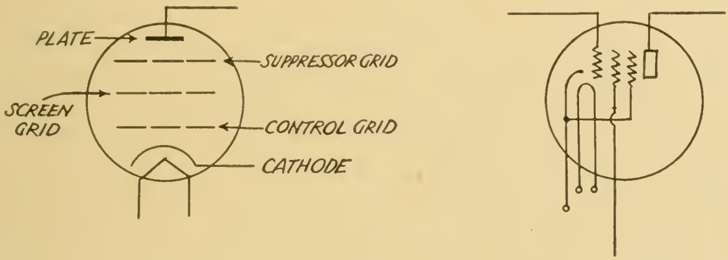


Fig. 136.—Five-electrode tube, or pentode.

A fifth element may be introduced into the tube to prevent secondary emission. That addition creates a five-electrode, or pentode tube. The fifth element is the "suppressor" grid, which is located between the screen grid and the plate, and is negatively charged. The suppressor grid discourages secondary emission and drives any negatrons that may escape into the vacuum back to the plate again. It thus destroys the space charge that surrounds the plate in a four-element tube, and permits still further amplification per stage.

Suppressor grids commonly receive their negative charge through direct connection with the cathode. In some pentodes this connection is made inside the tube.

However, in the 57-type pentode tube shown in Figure 139, it is made at the socket terminals.

(19) The three-electrode tube is often called the "triode," the four-electrode or screen grid tube is the "tetrode," and the five-element tube is a "pentode."

"Class A" and "Class B" Circuits

(20) Amplifier circuits may be either Class A or Class B. The difference is a matter of grid bias, but the constants of coupling transformers and other apparatus must be adapted to the type of amplification used. Class A amplification is the kind we have been considering up to this point, in which the grid is always negative, and made a little more or a little less negative by the speech a. c., and the milliamperage of the plate current varies or "swings" around a medium level. Circuits designed to operate in Class B commonly have a low grid bias, and when speech a. c. is added the grid "swings" positive during part of the cycle. In some Class B circuits there is no grid bias at all, and the grid is positive over full one-half of the speech current cycle. The plate circuit constants are so adjusted that there is a little flow of plate current while the grid remains at all negative, and a sudden rush of plate current results when it swings neutral or positive. The circuit of Figure 134 is one used for audio-frequency Class B.

Tubes that were originally designed for Class A work can be operated as Class B by providing a very high grid bias; one so high that there is practically no plate current except during such time as the speech input is positive with respect to grid and the extremely negative bias is reduced accordingly.

The projectionist cannot expect to distinguish between Class A and Class B amplifiers by looking at them, or in most cases, even by studying their wiring diagrams. Manufacturers, however, grade their amplifiers as Class A or Class B. The large majority of theatre amplifiers are Class A.

Class B gives greater power per tube than Class A, which can be understood when it is remembered that in

Class A amplification the a. c. component of the plate circuit is a comparatively small ripple upon the underlying d. c., while in Class B the "plate swing" is much greater; sometimes, as said above, the Class B plate current may vary from nearly nothing to the maximum during each alternation of the grid bias. Because of this difference small tubes can be used to provide sound for a moderately large theatre but the gain in economy is paid for in some sacrifice of quality.

(21) Class AB, sometimes called Class A Prime, represents a compromise between the two kinds of amplification above described. The grid bias is so adjusted that the grid charge will always be negative with low or medium volume, but at high volume the grid swings positive during part of the speech cycle. At low volume the tube will operate in Class A; at high volume in Class B.

All the foregoing represent essentially minor variations of the fundamental circuits shown in Figure 128, which are basic to every type of amplifier whatsoever.

It should be mentioned that these variations are combined in all possible ways. The same amplifier may have one stage of Class A and another stage of Class B, just as it may have condenser coupling between tubes at one point, and transformer coupling between another two tubes. The combination in one amplifier of single-tube stages such as Figure 128 with push-pull stages such as Figure 134 is extremely common. But Figure 128 still remains the foundation of all amplifying circuits. No superficial variations alter that fundamental fact.

Amplifiers and Their Power Supplies

Figure 130 represents a complete amplifier, and there are still amplifiers in theatre use that resemble Figure 130 in needing power supplies from an external source. The modern practice, however, is to build the power supply equipment into the amplifier cabinet. Thus a modern amplifier includes not only the circuits explained above, but also a rectifier arrangement to convert 110-volt a. c. to the d. c. of various voltages required by the tubes. We are now ready to inquire in detail into the power requirements of amplifying tubes.

Plate Power Supply

(22) The plate of the amplifying tube uses d. c. only. In this the amplifying tube again differs from the rectifying tube. The function of the rectifying tube is to convert a. c. to d. c., and a. c. is applied to its plate for that purpose. But the function of the amplifying tube is to superimpose an a. c. ripple on steady d. c. Alternating current cannot be used for the plate supply of amplifiers, and the d. c. that is used must be extremely steady and pure. Any ripple it might contain would be heard in the loud speakers as sound.

The plate voltage runs from about 90 volts for small tubes up to about 1,000 volts. The maximum current per tube is something under 100 milliamperes, while the smallest tubes have a plate current of about 1 milliampere.

(23) Plate power for amplifiers is provided from any of four sources. Dry batteries are used for small tubes, particularly for those of photo-electric cell amplifiers mounted on or near the projector. Storage batteries with a total of 350 volts have been used in some systems, although this method is substantially obsolete. High-voltage generators enjoyed a certain vogue, but are also obsolete or rapidly becoming so. The fourth method, now universally favored, is that of the built-in rectifier, using rectifying tubes as a rule, although occasionally "stack" or "disc" rectifiers (see Page 287) are encountered. Line a. c. is supplied to a power transformer built into the amplifier. A. c. drawn from the high-voltage secondary of this transformer is rectified, filtered, and supplied to terminals "B" of Figure 128. These terminals may actually exist in the amplifier, or wires may run solid from the rectifier filter to the amplifying tube sockets, since there is no real necessity for terminals when the power supply is built into the same cabinet or panel. If the panel carries amplifier tubes of more than one type,

requiring more than one voltage for plate power, the rectifier supplies the highest voltage necessary, and power for the smaller tubes is obtained by means of voltage drop through resistors included in the rectifier output circuit for that purpose. Screen grid voltage, which is commonly lower than the plate voltage of the same tube, is secured in a similar way. Sample plate supply circuits are traced in detail on Pages 556 and 564.

Filament and Heater Supply

(24) Filaments may be heated by either a. c. or d. c., depending on the type of tube, while indirect heaters are usually supplied with a. c. Direct current is compulsory for the smaller filaments. Filament and heater voltages are usually low, not more than ten volts. Current requirements range from a quarter of an ampère to about three amperes. One Western Electric rectifier tube, however, uses six amperes at fourteen volts. D.-c. applied to the filaments of small tubes may be filtered to remove ripple.

(25) Four methods of providing heater or filament power are in common use. One is the external storage battery. Another is the external motor-generator, and a third the external rectifier. All these provide d. c. The commonest method provides a. c., and consists of a transformer with a low-voltage secondary and a 110-volt primary, built into the amplifier.

Very often this transformer, and the plate supply transformer mentioned above, are the same instrument. The same transformer can have more than one secondary, and it is common practice to provide a high-voltage secondary, consisting of many turns of wire, and one or more low-voltage secondaries, with comparatively few turns of wire, all on the same core. Such secondaries operate independently of each other. The voltage delivered by each secondary will be governed entirely by the ratio between its turns and the number of turns on the primary.

Grid Bias Supply

(26) The grid bias must be smooth d. c. The voltage required is a small fraction of the plate voltage needed for the same tube. The current required in Class A is zero, since the "load" of the grid circuit is a condenser, through which d. c. does not flow. In Class B circuits there will be some flow of grid current when the grid swings positive.

(27) There are three methods of providing grid supply. The simplest is by use of a small dry battery, called the "C" Battery. This would connect to terminals "C" of Figure 128, negative to grid, and positive to cathode. A second method uses a voltage drop introduced into the d. c. filament supply (Figure 137). A resistor is wired in series between the negative side of the filament and the negative pole of the filament supply battery or other d. c. source. The grid is wired to the negative side of that resistor, and is therefore negative with respect to filament by the extent of the voltage drop the resistor creates.

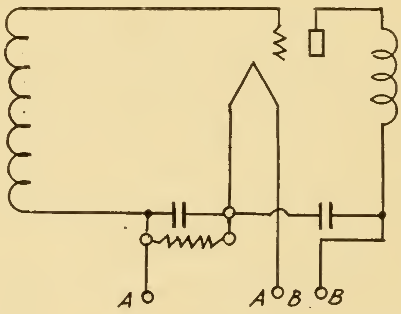


Fig. 137.—Method of obtaining grid bias by voltage drop in filament circuit.

The method of Figure 137 is not applicable to large tubes that need a grid bias of higher value than their full filament voltage. The circuit of Figure 138 is used with such tubes, as well as with heater types. The resistor shown in that diagram is in series with the plate or "B" circuit. The grid of Figure 138 is negative with respect to cathode by the extent of the voltage drop through the resistor.

Details of Common Amplifier Circuits

All of the foregoing can be illustrated, and any details that may still seem dubious will perhaps be made clearer, by detailed analysis of the circuits of actual theatre amplifiers. Figures 139 and 140 have been chosen for this purpose. They represent two amplifiers that are perhaps the most widely used at the present time.

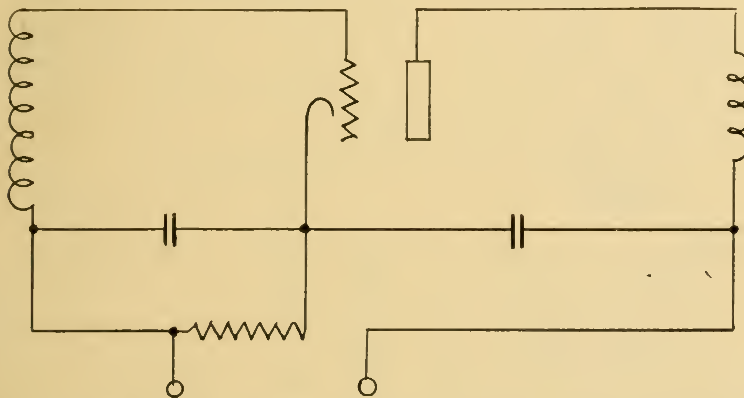


Fig. 138.—Method of obtaining grid bias by voltage drop in plate circuit.

Circuits of Figure 139

At the bottom of Figure 139, near the right-hand corner, are two arrowheads that show connection to a 110-volt power line. Above them is the power switch of the amplifier, through which the 110-volt circuit runs to the primary or right-hand coil of the power transformer, T-3.

T-3 has four secondaries, shown to the left of the three vertical lines that represent its core. The top secondary lights the filaments of the two type 80 recti-fier tubes. Just below this is the long (high voltage) secondary that supplies plate power to those tubes, and through them to the amplifying tubes, as we shall see. Below this again is a secondary winding terminating in two arrowheads. To the left of the upper arrowhead is

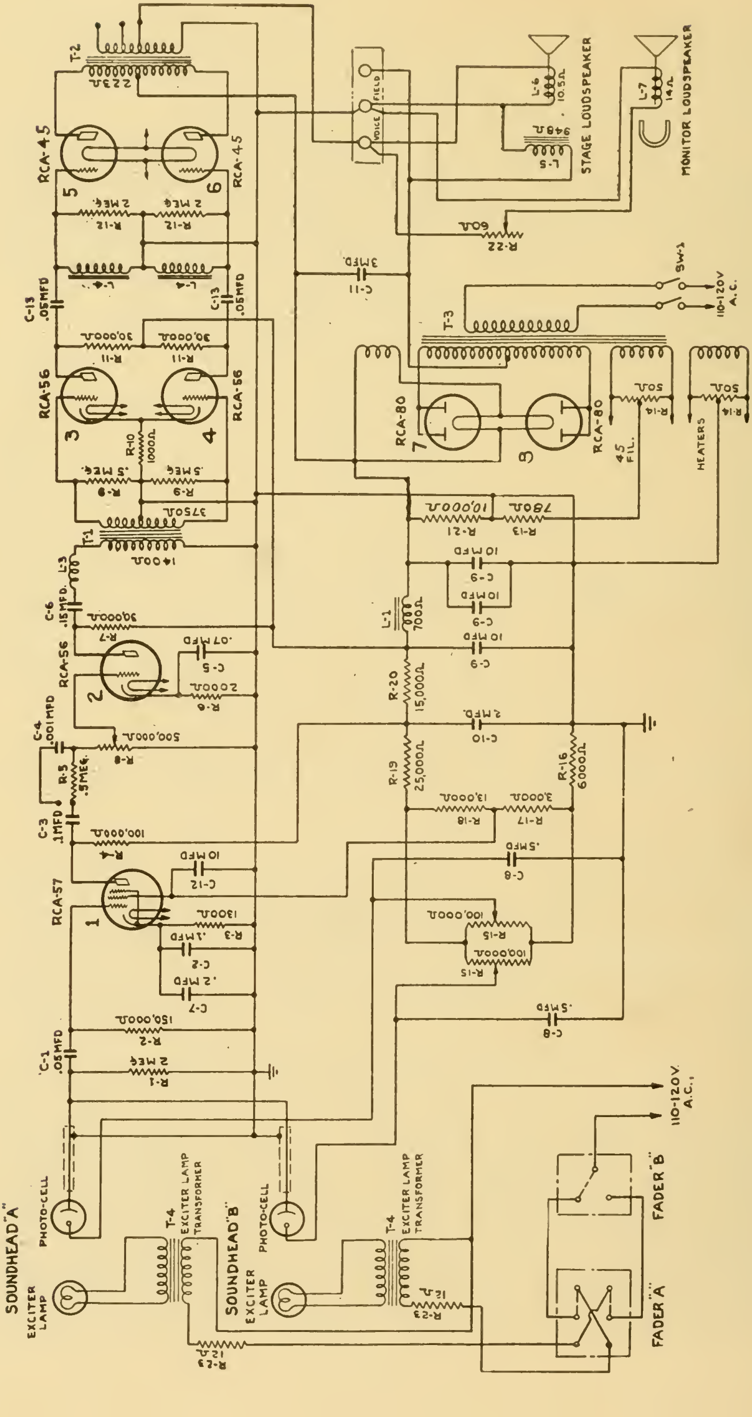

SOUNDHEAD "A"
EXCITER LAMP
PHOTO-CELL
T-4
EXCITER LAMP TRANSFORMER
SOUNDHEAD "B"
FADER "A"
FADER "B"
110-120V A.C.
RCA-57
RCA-56
RCA-45
RCA-80
T-1
T-2
T-3
STAGE LOUDSPEAKER
MONITOR LOUDSPEAKER
VOICE
FIELD
SW-1
45 FIL.
HEATERS

FIGURE 139

the notation, "45 Fil." which indicates that this winding heats the filaments of the type 45 amplifying tubes (top right of the drawing). Glancing at those tubes we see that their filaments also terminate in arrowheads. This is a common method of showing filament circuits. Drawing in the connecting wires would complicate the diagram without giving any additional information. Let us return to the transformer. The winding that supplies the "45" filaments is bridged by a center-tapped resistor, the function of which will be seen later. The lowest secondary of this transformer supplies power to the heaters of the other four tubes. This coil also is shunted by a resistor, the center-tap of which is grounded. Tracing the wire from the center-tap we see that it runs without interruption to the ground connection. An open-circuit in this ground connection might cause the amplifier to hum.

The rectifier tubes shown just to the left of the plate secondary of T-3 happen to have two plates each. One of these tubes is sometimes used alone as a full-wave rectifier. But in this circuit the plates are connected together and act as a single plate; each tube acts as a half-wave rectifier, the two being combined in a full-wave rectifying circuit. (Page 501.) The positive side of the d. c. circuit leading from these tubes is, of course, the wire leading from their filaments, and the negative side is the wire running to the center-tap of the plate or high-voltage secondary. Tracing one branch of this circuit from positive to negative: from the filaments of the rectifier tubes left about ¼ inch, up one inch, left ⅛ inch, down ¼ inch, and left about one inch to the filter choke coil, L-1. At both sides of this choke coil the line is bridged by filter condensers C-9. We continue to follow the positive line through R-20 and R-19, to the point where it turns downward about an inch and a half left of R-19. Thence the circuit runs through Resistors 15, downward and right, through R-16 and still further right, then upward for two inches, right for two inches, and down an inch to the center terminal of the speaker terminal strip. Thence down about an inch, left a quarter inch and down through L-5, the field winding of the stage speaker, which thus does double duty, serving as a filter choke also. Thence left and then upward about an inch, left an inch and a half, and down an inch to the center-tap of the high-voltage secondary, which is the negative terminal of this circuit.

We can now look at some of the branch lines that lead from this circuit to provide plate power for the photo-electric cells and the amplifying tubes, and screen-grid bias for the RCA-57 tube.

Plate Power for RCA 45 Tubes

From the filaments of the rectifier tubes left a trifle and then upward about an inch. Thence, instead of turning left to filter choke L-1 we now branch upward another half inch, right about two inches, and upward to the center-tap of T-2 output transformer. Thence to the plates of the 45 tubes, and (we are tracing from positive to negative) through these tubes to their filaments, and through the arrowhead connections to the 50-ohm resistor that bridges the 45 filament supply secondary of the power transformer, T-3. From the center-tap of that resistor left and upward to the lower, or positive, side of R-13. From the upper or negative side of this resistor (the voltage drop through which provides grid bias for the 45 tubes) right a trifle, upward, right and down to the center terminal of the speaker terminal strip, and thence through the speaker field coil to the center-tap of the plate secondary of T-3. The speaker field coil and condenser C-11 constitute the only filter in this branch of the circuit.

Plate Power for RCA 56 Tubes

A line branching upward from the left-hand side of choke coil L-1, through Resistor R-7 to the plate of one of the three 56 tubes. From the cathode of that tube downward through the grid bias resistor R-6, right about three and a half inches and downward through the speaker field coil to negative. This line is filtered by L-1 and its associated condensers as well as by the field coil.

Another branch of the same line, instead of going upward to R-7, turns right, and then upward through resistors R-11 to the plates of the push-pull 56 stage. From the cathodes of that stage through the bias resistor R-10 and left still another half inch, then down about an inch and right and down through the stage speaker field to negative.

Plate Power for the 57 Tube

From the left-hand side of L-1 left through R-20, then up, left and up through R-4 to the plate of the RCA-57. From the cathode of that tube through the bias resistor R-3, and thence right about six inches and back to negative through the speaker field.

Screen Grid Bias for the 57 Tube

From the left-hand side of R-20 left through R-19 and then down through R-18. From the lower end of R-18 left, up, left and up to the screen grid of the 57. The return to negative is through the cathode of that tube as before. The screen positive voltage is lower than that of the plate to the extent of the drop through the "voltage divider" resistors R-19 and R-18. (The screen voltage is 40; the plate voltage 121.) The screen grid circuit is not intended to carry appreciable current. The majority of the emitted negatrons in the tube go to the more positive plate. The greater part of the current through R-18 does not complete its circuit through the screen grid, but returns to negative through R-17 and R-16.

Plate Power for Photo-Cells

From the left-hand side of R-19 left and then downward to the two resistors R-15. Through these resistors and then down, right, through R-16, right, up, right and down through the speaker field. Through the arrowhead variable contacts to resistors R-15 to the anodes of both photo-cells. The purpose of these variable contacts is to compensate for small inequalities in the photo-cells or in their exciting light, and thus produce equal volume from both projectors. From the cathode of whichever photo-cell is illuminated (the other, being dark, is the same as an open switch) through the shielded cable to the upper end of the coupling resistor R-1. Through R-1, then right about seven inches, and down to negative through the speaker field. The supply to this circuit is still further filtered by the bridging condensers, C-8.

Grid Bias Resistors in Figure 139

Every amplifying tube of Figure 139 receives control grid bias by virtue of the voltage drop across a resistor that is connected in series with its plate circuit. (Page 553.) Having traced all the plate circuits we have encountered all those resistors. They may be listed here for convenience, as follows: for the 57 tube, R-3; for the single 56 tube, R-6; for the push-pull 56 tubes, R-10. These resistors are shown close to their respective cathodes. The bias resistor for the 45's is shown just left of the lower rectifying tube. It is R-13.

Speech Circuits and Frequency Control

The speech voltage of the photo-cell circuits is condenser-coupled to the 57 tube. The greater part of the a. c. component created by the photo-cell action completes its circuit through C-1 and R-2, only a relatively small portion flowing through the high resistance of R-1. The a. c. potential difference thus developed across R-2 is impressed upon the grid and cathode of the 57.

The a. c. (speech) return through R-3 is by-passed by condensers C-2 and C-7. These condensers favor the high-frequency response of the amplifier, inasmuch as they provide an easy path for the high frequencies while low frequencies must suffer loss of power in passing through 1,300 ohms of R-3. Open-circuiting either or both of these condensers destroys that discrimination and reduces the percentage of high frequencies (which is the same thing as increasing the percentage of lows).

The 57 is condenser-coupled to the 56, through C-3 and Resistors R-4 and R-8. R-8 is the volume control of this amplifier. The sliding contact shown in the drawing is represented in physical fact by a knob on the front of the amplifier panel. C-4 and R-5 are frequency regulators. By bridging the condenser C-4 a path of lower resistance is offered to the high frequencies which is equivalent to decreasing the percentage of low frequency response.

The 56 tube is transformer-coupled to the first push-pull stage, but the plate d. c. supply is kept out of the transformer windings by use of Resistor R-7 and Condenser C-6, the a. c. component flowing through the capacitor C-6, the reactance L-3 and the primary of T-1. The transformer has a voltage step-up, and its use increases the grid swing of tubes 3 and 4. L-3 is added to adjust the frequency response.

The push-pull 56 tubes are coupled to the push-pull 45 tubes through the condensers C-15 and reactors L-4, the constants of which are chosen to give the amplifier the desired frequency response. The primary of T-2 output transformer carries the plate d. c.

The secondary circuit of T-2 is easily traced through the speech windings of the stage and monitor speakers. The latter is of the "magnetic" type. (Page 586.) Rheostat R-22, shown left of and somewhat above the stage speaker field, is used to control the volume of the monitor speaker.

Condenser C-11, just left of the speaker terminal strip, serves as part of the ripple filter. The two condensers C-8 keep the photo-cell a. c. component out of the rectifier.

The extreme left-hand portion of Figure 139 does not, properly, deal with the amplifier at all, but represents the exciter lamp power supply. The lamps are lit with a. c., the frequency characteristics of the amplifier being such that the 120-cycle hum created is filtered out in the coupling circuits and does not reach the speaker. T-4 are step-down transformers developing 10 volts for the lamp filaments. Fader "A" is a double-pole double-throw switch and Fader "B" is a single-pole double-throw switch. One is mounted to the right of each projector in convenient operating position. (See Figure 141.) No matter which exciter is lit at the moment, or how the switches happen to be set, throwing either switch over will turn out the lamp of the projector then operating, and simultaneously light the other, thus effecting change-over of sound at the end of each reel.

Figure 139 illustrates many of the fundamental principles of amplifier circuits that were discussed in the preceding parts of this section on Amplifier Theory and Wiring, and at the same time shows how designing engineers vary and combine the application of those principles. The use of coil L-4 in Figure 139 represents one such variation. Condensers C-7 and C-2 represent another. The reader must always expect to find some novelty in any amplifier diagram he may have occasion to trace. Some will be found in Figure 140.

The Circuits of Figure 140

In this widely used amplifier two noteworthy features are found in the switching arrangements and binding posts of the lower left-hand corner. In this area of the drawing fuses F-1 and F-2 mark the terminals through which 110-volt line power is supplied to the amplifier. Tracing this pair of wires straight right, through the switches D-1 and D-2, we see that they terminate at the primary windings of two power transformers, T-4 and T-5. A glance at the secondaries of these transformers shows that T-5 is the high-voltage instrument providing plate power, since its secondary is wired to the plates of vacuum tubes V-5 and V-6. However, these tubes seem to have grids grounded to their plates, a peculiarity of interest, worth returning to consider. Meanwhile, we note that T-4 has two secondaries. The right-hand one lights the filaments of the two tubes V-5 and V-6, while the left-hand secondary lights the filaments of tubes V-3 and V-4, which apparently are wired in a push-pull stage. Whether or not this is really the case is a question that can be deferred until the speech circuits of those tubes are traced. It is a prime mistake, in analyzing the wiring drawing of an amplifier, to try to see too much at one time. At present we are tracing

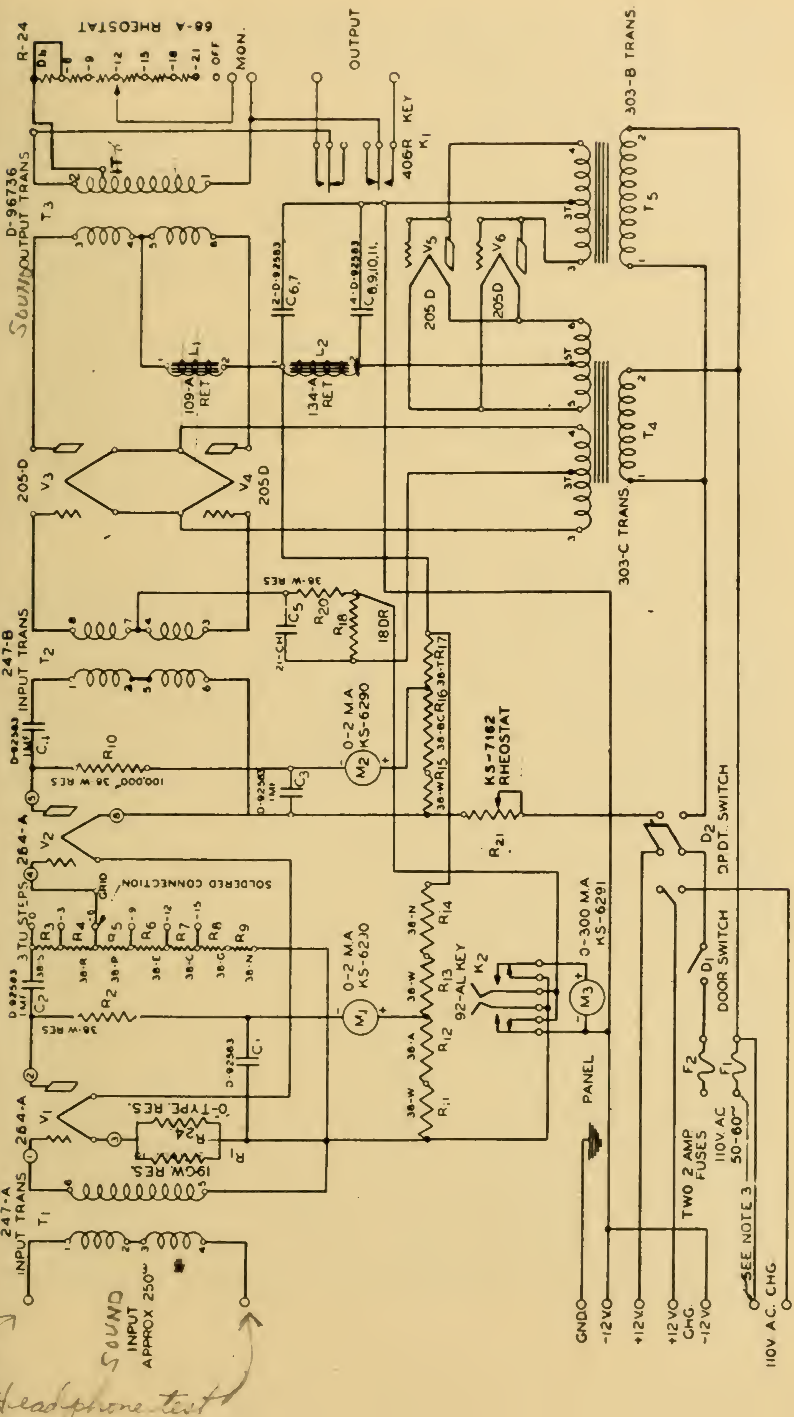

247-A INPUT TRANS T1
INPUT APPROX 250~
264-A V1
19 GW. RES.
O-TYPE RES.
R24
3 TU STEPS
SOLDERED CONNECTION
264-A V2
0-2 MA KS-6230
0-2 MA KS-6290
247-B INPUT TRANS T2
100,000 38 W RES
38-W RES
18 DR
205-D V3
V4 205D
109-A RET L1
134-A RET L2
D-96736 OUTPUT TRANS T3
R-24
68-A RHEOSTAT
MON.
OUTPUT
406R KEY K1
205 D V5
205D V6
303-C TRANS. T4
303-B TRANS. T5
KS-7162 RHEOSTAT
R21
0-300 MA KS-6291
92-AL KEY K2
PANEL
TWO 2 AMP FUSES
110V. AC 50-60~
SEE NOTE 3
DOOR SWITCH D1
DP DT. SWITCH D2
GND
-12V
+12V
+12V CHG.
-12V
110V AC. CHG
Sound
Head-phone test

FIGURE 140.

the a. c. power line, which is a short and simple circuit. The switching arrangements near the fuses, however, remain to be considered.

D-1, labelled "Door Switch," is obviously a safety arrangement, a single-blade, single-throw cut-out that opens when the door of the amplifier is unlatched. Its function is to protect the projectionist against the high voltage generated by the secondary of T-5. At this point it may be well to remark that no safety switch offers complete protection. Not in an amplifier. True, that T-5 no longer generates high voltage when switch D-1 is opened; but the voltage previously generated is stored in the condensers of the rectifier filter, and remains there after the safety switch is opened. To render this amplifier wholly harmless the filter condensers must be discharged. This is done by short-circuiting them using a screw driver blade with an insulated handle.

The double-throw switch, D-2, to the right of D-1, removes the line power from the two power transformer primaries and throws it over to the terminals at the extreme bottom left of the drawing, marked "110V. A.C. Chg." This switch, then, turns off the amplifier and turns on the battery charger. To complete our understanding of the workings of this switch we must look at the 12-volt d. c. terminals immediately above the charger terminals.

The d. c. output of the battery charger, 12 volts positive and negative, is wired to the terminals so marked, just above the 110-volt charger input terminals. Now, when switch D-2 is thrown to the right the positive side of the charger's d. c. output is open-circuited at switch D-2, and we know also that the 110-volt input to the charger is interrupted. When switch D-2 is thrown to the left, input power is supplied to the charger, and the positive side of its d. c. output is connected, through the upper blade of D-2, to the 12-volt positive battery terminal, just above the 12-volt positive charger terminal. The drawing also shows a permanent common connection between the negative of the battery and the negative of the charger output, therefore no switching is needed in the negative line.

Switch D-2 is evidently extraordinary in its wiring. A two-blade, double-throw switch, its lower blade switches 110-volts a. c., and its upper blade switches 12 volts d. c. In physical fact it is a rotary switch, having the positions "off," "operate" and "charge." In the "off" position the switch is open, as it is shown in the drawing. The "operate" connections are those which the switch in the drawing would make if thrown to the right, closing the circuit of the line a. c. to the power transformers and connecting the positive leg of the 12-volt d. c. to the internal wiring of the amplifier. The "charge" position is that of the same switch thrown to the left in the drawing, in which both line a. c. and 12-volt d. c. are disconnected from the amplifier and connected to the battery charger.

D. C. Filament Circuit of Figure 140

Assuming that switch D-2 has been thrown to the right, or "operate" position, let us trace the 12-volt circuit through the wiring of this amplifier.

From the 12-volt battery terminal (the upper of the two 12-volt positive terminals) the line runs right through switch D-2, then upward through R-21 rheostat, and thence upward to the filament of V-2. Through this filament, then down, left and up to the filament of V-1. Through the filament of V-1 and down through the two bias resistors, R-1 and R-24; then down and right to the 92-AL key switch, K-2. Through the two right-hand contacts of this switch to the milliammeter M-3, and thence left to the negative 12-volt terminal.

Switch K-2 needs a word of explanation. As shown in the drawing, it places the milliammeter in series with the d. c. filament circuit, using that instrument to show whether filament rheostat R-21 has been correctly adjusted. But when this key switch is thrown, the two central prongs are spread apart. The upper arrowheads then make contact with the central prongs, and the lower arrowheads are isolated. In that position of the switch the battery circuit we have just traced runs through the left-central prong to the left-outside prong, and thus returns to negative without passing through the milliammeter. The meter, as we shall see, is then used for another purpose.

We have already glanced at the a. c. filament circuits of the other four tubes, in the course of tracing the a. c. power line.

Grid Bias of V-1 and V-2

The grid bias of V-1 is obtained by means of the drop through resistors R-1 and R-24. The grid of V-1 connects to the filament circuit at the negative side of those resistors. The bias of V-2 is obtained through the same resistors, plus the drop in the filament of V-1. The grid of V-2, as can be seen by tracing its wiring, also returns to the common filament circuit at the negative side of R-1 and R-24.

To be more accurate, the grid bias of V-1 consists of half the voltage drop across the filament V-1, plus all the drop through R-1 and R-24. The bias of V-2 consists of half the drop across the filament of V-2, plus all the drop through the filament of V-1, plus all the drop through R-1 and R-24.

The grid bias of the push-pull stage is obtained by means of voltage drop in its plate circuit, as will be seen shortly.

Plate Supply Circuits of Figure 140

Tubes V-5 and V-6, at the lower right of the drawing, are the rectifier tubes, in spite of the fact that they contain grids. The manufacturer has used two Western Electric 205D amplifying tubes as rectifiers by the simple expedient of shorting the grid prongs of the sockets to the plate prongs. When connected in this way the grid is no longer a separate element in the tube, but simply a metallic extension of the plate, and as long as the tube remains in a socket so wired it is, and functions as, a two-element tube.

The two tubes, V-5 and V-6, therefore constitute a common full-wave rectifier circuit, identical in principle and action with those we have already seen in Figure 139 and in Figures 114 and 115. The positive d. c. lead is the one that connects to the filaments of the rectifying tubes, which in this case is the wire that runs upward from the mid-tap, terminal 5-T, of the right-hand secondary of the filament transformer. The negative terminal is the one that connects with the mid-tap of the plate or high-voltage secondary, the wire joined to terminal 3-T of the secondary of transformer T-5.

Tracing this supply circuit from positive to negative, we may begin at 5-T, the mid-point of the filament transformer secondary, and follow the wire upward to choke coil L-2. From either side of this choke coil its associated filter condensers, C-6, C-7, C-8, C-9, C-10 and C-11 are wired across to the negative side of the line, in a normal brute-force filter arrangement, such as we saw in Figure 115. Continuing upward from L-2, the line runs through another choke coil, L-1, to the mid-point of the primary winding of the output transformer. Through that winding to the plates of V-3 and V-4. From the filaments of those tubes to the left-hand secondary of the filament transformer, T-4. From the center-tap of that winding up, left and up to the left-hand or positive side of the bias resistor, R-18. From the right-hand, or negative side of that resistor down at a slight angle, left, down and left to the key switch, K-2. As that switch appears in the drawing, this circuit is closed through its two left-hand contacts, and continues down, right, up, right, and down to the mid-tap (3-T) of the plate transformer secondary, its negative terminal.

When the position of switch K-2 is changed, the two central prongs are spread apart and make contact with the upper arrowheads, while the lower arrowheads are open-circuited. Then the circuit we have just been tracing runs upward through the right-hand central prong, through the right-hand upper arrowhead, down and through the milliammeter, and thence down, right, up, right, and down to the center tap of the plate transformer secondary. With the switch in this position the meter reads the plate current through tubes V-3 and V-4.

To trace the plate circuit of the other two tubes, we return to the upper end of choke coil L-2. From this point a wire runs left, down and left to the right-hand side of Resistor R-17. From the left-hand side of this resistor a branch circuit leads upward, left and upward, through plate current milliammeter M-2 and through Resistor R-10, to the plate of the Western Electric 264-A tube, V-2. The return is through the filament of that tube. The negative leg of the plate circuit we are now tracing joins the negative leg of the filament circuit previously traced at the left hand or negative side of the milliammeter M-3.

Returning to the right-hand side of R-17, we find a branch line running down, left and up to the right-hand side of Resistor R-14. Trace through R-14 and R-13, and then up through plate current milliammeter M-1 and through Resistor R-2 to the plate of V-1. The negative return is through the filament circuit.

R-14, R-13, R-12 and R-11 constitute a voltage divider, which is a resistance bridged across a line from positive to negative, and has as its voltage drop the full potential difference of the line. The desired percentage of that voltage drop is obtained for V-1 by connecting the wire leading downward from M-1 to a suitable point along the voltage divider. R-15, R-16 and R-17 constitute another voltage divider, also connected across the full voltage of the line. Connection is made to a suitable point for the plate power of V-2.

Speech Circuits of Figure 140

Speech input to the amplifier of Figure 140 is through the transformer at the extreme upper left of the drawing, T-1. The alternating speech voltage developed in the secondary of that transformer is connected directly across the grid and filament of the left-hand amplifying tube, V-1. The plate of V-1 is condenser-coupled to the grid of V-2. C-2 is the coupling condenser. C-1 is the plate circuit by-pass condenser (Figure 129) for V-1. Resistors R-3 to R-9 serve as volume control, precisely as does Resistor R-8 in Figure 139. (See also Figure 133.) The plate speech circuit of V-2 is coupled to the primary of transformer T-2 through Condenser C-4, while Condenser C-3 is the plate circuit by-pass condenser. The use of Condenser C-4 keeps the plate d. c. for V-2 out of the windings of T-2 primary. The reader should note the similarity between the plate circuit of V-2, in the drawing now under consideration, and the plate circuit of the single RCA-56, in Figure 139.

A glance at the speech circuits of V-3 and V-4 shows that these two tubes are in normal push-pull arrangement (Figure 134). R-18, as has already been said, is the grid bias resistor, the grids being connected to its right-hand, or negative side, while the filaments are wired, through the filament transformer secondary, to its left-hand, or positive terminal. C-5 is the grid circuit by-pass condenser, which makes it unnecessary for the a. c. component of this circuit to flow through R-20 and R-18.

The plate circuits of V-3 and V-4 contain nothing unusual, except the addition of choke coil L-1. Condensers C-6 and C-7 serve as plate by-pass, as well as filter, condensers.

The output circuit of Transformer T-3 contains a rheostat allowing for independent control of monitor volume, as well as a single-throw, double-pole switch through which connection is made to the stage speakers.

The reader will note that in spite of innumerable surface dissimilarities, the fundamentals of this circuit are are essentially like those of Figure 139. The same identity of fundamentals will be found in any amplifier wiring whatsoever.

Some of the surface differences between this drawing and Figure 139 refer to the use of different types of tubes. There is no pentode tube in Figure 140 like the RCA-57 of Figure 139. Figure 139, again, uses heater cathodes in its smaller tubes, and has no filament battery supply. It has no meter switches like K-2 because it does not use meters. The circuits of the two volume controls are identical, yet the physical arrangements are different. The volume control in Figure 139 is operated by means of a dial on the face of the amplifier. That in Figure 140 is set with a soldered connection, operating control of volume being provided by an external fader-volume control, such as that shown in Figure 125. The reader, comparing any two amplifier drawings, can easily find a dozen minor differences. But if he can teach himself to look for fundamentals underneath such surface modifications, he should find little difficulty in tracing and understanding the circuits of any of thirty-odd types of amplifiers now used in American theatres.

Care and Troubles of Amplifiers

(28) Amplifiers contain no moving parts aside from switches, controls, and, rarely, an automatic relay switch. Even these moving parts are not used steadily, but only once in a while, and therefore are exposed to very little wear. Consequently, amplifiers do not wear out. They do, however, contain one part that is subject to deterioration, namely, the tube, which is consequently arranged to be replaceable, and which must be carefully watched. Aside from tube deterioration there are two other general causes of trouble in an amplifier. One is dirt, resulting in bad contact in the switches, the controls, and the tube sockets. The other is overheating, a condition that causes several different kinds of trouble which are described further on.

Amplifiers, then, need care in respect to three items: tube deterioration, dirt and overheating. Amplifier troubles arising from any other cause are comparatively uncommon.

Care of Amplifier Tubes

(29) Tubes can go wrong in three ways, one being a burnt-out filament. But modern filaments very seldom burn out. They are made to stand up until long after the tube has become useless through decline of its emitting powers. A burnt-out filament is, moreover, a trouble that can be detected at a glance. Consequently the projectionist has little occasion to worry about it, provided proper care is taken to secure correct filament voltage. Excessive voltage, of course, will burn out any filament.

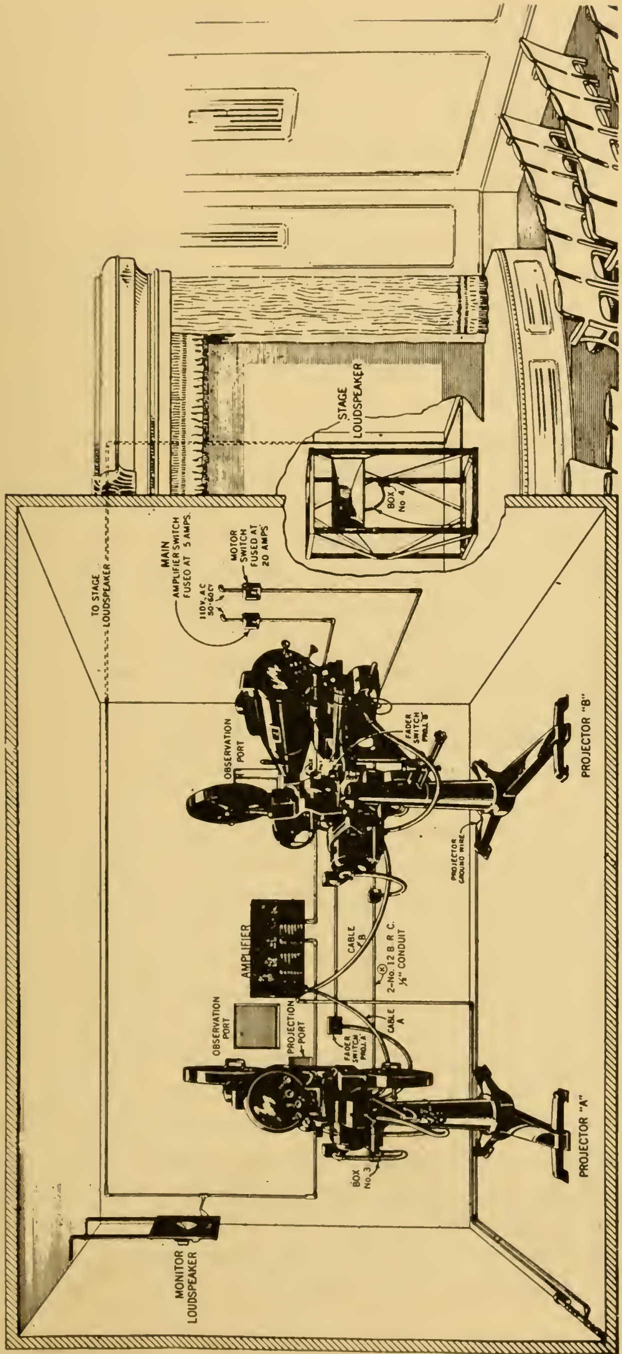


FIG. 141.—Projection room and stage installation. The amplifier seen between the projectors is the same diagrammed in FIG. 139.

In most amplifiers, filament voltage control is provided only in d. c. filament circuits. There it is necessary. The d. c. source is likely to be a storage battery, the voltage of which varies according to its state of charge. A filament rheostat is needed to insure that the voltage across the filament shall always be the same regardless of the condition of the battery.

Where filaments are lit by a. c., controlling rheostats are omitted as superfluous. The correct voltage is provided by the transformer and needs no adjustment as long as the power line voltage does not fluctuate.

In many houses, however, the line potential may vary from 85 to 135 in the course of one evening. This will happen wherever the local power house is underequipped, cannot maintain full output during the peak load of early evening, and does not cut down its output quickly enough when the peak load has passed. In such cases, which are common, the remedy is not to install a rheostat in the a. c. filament circuits, but to install a voltage control rheostat or transformer in the power line. If tubes are subjected to prolonged high voltage, even the heavy filament of a large tube is likely to burn out.

Much more common than the burning out of a filament is loss of the power of emission. This happens sooner or later to all tubes. While "rejuvenation" is possible, the method employed for that purpose varies greatly according to the type of filament involved, moreover, a mistake in rejuvenating is likely to result in stopping a show when the rejuvenated tube is put back into use. The common practice is to discard tubes when once they have lost emitting power. Tubes are no longer so expensive as to justify the time, effort and risk involved in attempting to restore them after they have worn out.

Loss of emitting power is revealed by a decline in plate current reading, plate voltage and grid bias remaining unchanged. It is usual to assume that those voltages have not altered, and merely to install a new tube whenever one in use shows low space current. Only when a series of new tubes all show low space current is it worth while to check the supply voltages.

In Figure 140, meter M-1 will reveal loss of emitting power in tube V-1, while meter M-2 provides a similar check upon tube V-2. Tubes V-3 and V-4 present a different problem. Meter M-3 (by use of switch K-2, as previously explained) reads the current through both these tubes, and if that current is low either tube may be at fault. The procedure then is to lift each of those tubes from its socket, momentarily, and watch the drop in the indication of meter M-3. The larger drop indicates the better tube, that is, the tube that was carrying nearly all the current. A slight drop indicates that the tube lifted from its socket* at that moment was not doing much work anyway.

It is good practice to "match" push-pull tubes. A number of new tubes should be tried in the sockets of V-3 and V-4 until a pair are found that give substantially the same change in the indication of meter M-3 when either is lifted from its socket. Pairs matched in this way should be kept in the spare parts cabinet, and when a change is necessary a matched pair should be inserted, while the good tube of the discarded pair may be kept and matched up, at some convenient time, with another tube of equal emitting power. The same procedure may be followed with the paired 56's and 45's in Figure 139, if a tube-meter is available.

Rectifier tubes also lose their emitting power, and if either V-5 or V-6, of Figure 140, has deteriorated, that fact will be made evident by low reading of all three milliammeters. Full-wave rectifier tubes should also be paired, the test procedure being the same as that for push-pull amplifier tubes, namely, to lift each tube from its socket momentarily and read the result on a plate current meter. In Figure 140 M-3 will serve this purpose also.

Matching paired tubes secures the best quality of sound. In the case of rectifier tubes, using an unmatched pair may possibly endanger other equipment. The secondary of T-5 transformer, in Figure 140, might burn out

* Make this test quickly. Do not keep the tube out of contact with its socket prongs for more than a second at most.

if tubes V-5 and V-6 are seriously mismatched. That half of the secondary that serves the better tube will be overloaded.

Figure 139 is typical of many modern amplifiers in that meters are not provided. Low space current may become apparent through decline of volume. A common method in such cases is to insert new tubes one at a time, until a sudden increase of volume shows that the bad tube has been replaced. This procedure, however, is neither accurate nor economical of tubes. A better way is to use a portable tube-meter. The theatre can afford to buy this instrument; it will repay its cost many times over in case of trouble; and without trouble will repay its cost in a few years by economizing on tube life. Service engineers dealing with amplifiers that do not have built-in meters carry such instruments. If the theatre is not receiving regular service a tube-meter can be borrowed or rented at the nearest radio repair shop.

High space current is less common than the reverse condition, but more dangerous. It may cause the amplifier to overload, distorting the sound, and it endangers every part (for example, resistor R-18 in Figure 140) through which the excessive current must flow to complete its circuit. There are three general causes of high space current. One is high line voltage, which, connected across the primary of T-5 in Figure 140, or of T-3 in Figure 139, will generate excessive voltage in the secondaries of those transformers. The remedy for this condition has been mentioned. A second cause is a "gassy" tube, which must be discarded. A third is low grid bias, which is the commonest cause in amplifiers that use "C" batteries.

We have seen in connection with rectifier tubes (Page 506) that inclusion of mercury vapor gas increases the emission. Argon or other gas is intentionally added to photo-electric cells for the same reason. But gas is highly undesirable in amplifier tubes for the reason that the positive ions are too large and heavy to respond readily to changes in the grid charge. The presence of gas in an amplifier tube therefore upsets the amplifying action, and renders the tube unsuitable for use. Amplifier tubes are carefully pumped to the highest possible vacuum, and when the pump has done all it can a charge of magnesium is exploded within the glass to absorb any remaining air. (This charge, depositing on the surface of the glass, causes the silvery layer seen on the inside of the tube.) But in spite of all precautions the crevices of the metal or graphite elements may retain some molecules of gas, that are dislodged when the tube becomes heated through prolonged use. The gas so released will injure the quality of the sound, but another objection to it lies in the excessive emission it may cause.

A blue glow partially filling the space of the tube, and flickering at high volume, indicates gas, but does not in itself indicate enough gas to be harmful. A strong blue glow combined with excessive plate current reveals a tube that should be discarded at once.

A steady or flickering blue glow in the glass itself does not indicate a gassy tube but only the presence of fluorescent materials in the composition of the glass, which have no effect on the tube action. To determine whether any glow seen is in the space between electrodes, and caused by gas, or only on the inner surface of the glass envelope and caused by harmless fluorescence, observe the tube carefully from several different angles.

Dirt in Amplifiers

Since the internal parts of an amplifier must heat somewhat with use, ventilation must be provided for them, and it is not possible to seal an amplifier so thoroughly that dirt will not get in. But the worst of all dirt for an amplifier is the fine carbon dust given off by the arc lamp. Carbon dust is the variable resistance used in the common type of microphone. Seeping into a sound switch or a volume control, or a filament rheostat, it will create variable resistance at those points, causing noisy sound. Perhaps the extreme seriousness of this type of trouble will not be plain to the reader (especially the beginner) unless he is reminded just how weak sound "power" really is. The power that fills every corner of a 4,000-seat theatre with loud, even thunderous sound, is not enough to light a 50-watt lamp. Yet even this represents an amplification of from ten to one hundred million over the original power delivered by the photocell. An extremely small amount of carbon or other dust in a switch contact, or a rheostat, or on the prongs of a vacuum tube socket, can create extremely disturbing noises in the loudspeakers of any theatre.

The remedy is to keep all switch contacts, rheostats, volume controls, vacuum tube socket prongs, and so on, scrupulously clean. Carbon tetrachloride is commonly used for this purpose because it dissolves grease readily, and it is only grease that holds dust to one place and prevents it being blown away. Chemically pure carbon tetrachloride gives better results than Carbona, which contains the same ingredient. The liquid of the projection room fire extinguisher also contains carbon tetrachloride—but don't rob the extinguisher, that may turn out to be suicide. Sound contacts should never be filed unless they are burnished afterwards. A very thin layer of vaseline is sometimes used to protect brass contact studs from becoming scratched. The thinnest possible film of vaseline is applied. This film is washed away periodically with carbon tetrachloride to prevent accumulation of dirt, and a new one applied.

(30) Dirt is not the only cause of bad contact in an amplifier. Another is loose spring tension. Spring tension is used at a number of points. The contacts of switch K-2 in Figure 140, for example, are held in position by the tension of the switch prongs. The sliding contacts of rheostats and volume controls (Figure 125, for example, as well as R-8 in Figure 139 and R-21 in Figure 140) are matters of tension. And it is spring tension that makes every contact of every tube with its socket.

Contact tension may be destroyed by dirt, which has temporarily held the spring out of its correct position, or by use, or by the heating of nearby parts. It must always be watched, and restored as necessary. Restoration of spring tension is unfortunately not easy. In the case of K-2 of Figure 140 a special tool is needed to do a really good job of adjusting prong tension, and in the absence of that tool an extraordinary degree of care is essential. Careless work will result only in a bent prong, permanently useless. Much the same is true of rheostat and socket adjustments, except that with such apparatus care alone, without special tools, is usually all that is needed.

Poor soldering, especially during a hurried repair job, is another cause of loss of contact in amplifiers. Proper soldering for sound circuits is discussed on Page 659. The kind of soldering that is quite satisfactory for a 110-volt power line is not nearly good enough for the low-current speech circuits of an amplifier.

(31) It has already been explained that bad contact in an amplifier can result in noisy sound. It should scarcely be necessary to add that extremely bad contact may result in an open circuit in which all sound is lost.

Overheating in Amplifiers

(32) Two of the three chief categories of amplifier trouble, bad tubes and dirt, having been discussed in some detail we can now turn to the third major cause of trouble, which is overheating.

Overheating destroys the vulcanizing of rubber insulation and bakes the grease out of cotton insulation. Eventually it chars the cotton. All these conditions tend to the development of a short circuit. Overheating is very likely to boil the insulating compound out of transformer or condenser casings, leading to ultimate breakdown of those instruments. When extreme and prolonged it changes the crystallization of copper wire and may cause the wire to break, creating an open circuit.

The principal cause of overheating in amplifiers is excessive line voltage.

Hum in Amplifiers

(33) Hum at the frequency of the power line can be caused by three conditions. One is a defective rectifier tube. If either V-5 or V-6 in Figure 140 should burn out, or if the emission in either tube should so far decline that

the tube is essentially useless and the rectifier is a half-wave rectifier, hum might follow. Filter coil L-2, and condensers C-6, C-7, C-8, C-9, C-10 and C-11 are not intended to smooth the heavier ripple of a one-tube rectifier. This condition, however, would also manifest itself in substantially lower plate current, and therefore in lower volume; consequently it could not escape detection for any great length of time.

Hasty repairs, in which wires are misplaced, can also result in amplifier hum. The wires of a sensitive sound circuit should never be placed in close inductive relation to an a. c. line, or to wires carrying the unfiltered output of a rectifier. Amplifier wiring is always planned to prevent inductive hum, and if it is disturbed for any reason must be replaced precisely as the manufacturer intended.

An uncommon but occasional cause of hum is a temporary defect in the power transformer, T-3 of Figure 139, or T-4 and T-5, especially T-5, in Figure 140. The iron core of a transformer is not a solid piece of iron, but is composed of a great many thin iron plates, called laminations. The laminations are held rigidly together by nuts and bolts, or by rivets, and if a bolt or a rivet should loosen, will vibrate in resonance with the frequency of the circuit. Such vibration increases the ripple in the rectifier output to a point where the filter cannot remove all of it. Tightening the holding bolts or the rivets will remove hum arising from this cause.

Amplifier Feed-back (noise)

(34) It was explained on Page 545 that an attempt to force excessive volume from a single tube might cause feed-back between the plate and grid circuits, resulting in distortion and possibly in motor-boating or howling. Feed-back between different tubes that have the same power supply is also possible, and without reference to excessive volume. If, for example, the plate a. c. of V-3 and V-4, in Figure 140, should in some manner find its way back to the plate circuit of V-1, Figure 140 would no longer act as an amplifier but as a

generator of alternating current or "oscillator." The frequency of the a. c. thus created would be determined by the resonance point of the circuits involved, and might be low enough to sound like motor-boating or high enough to sound like a high-pitch squeal.

Now the plate supply for tubes V-3 and V-4 comes from the same rectifier that provides plate power to V-1. If the a. c. component of the plate circuit of V-3 and V-4 passed through that rectifier some of it would be "fed back" to the plate circuit of V-1, and the amplifier would "oscillate." One of the functions of the plate by-pass condenser (Figure 129) is to prevent this by keeping the a. c. component of any plate circuit out of the rectifier that provides the plate d. c. supply. Therefore an open-circuited by-pass condenser can cause feed-back and hence oscillation (motor-boating or howling) in an amplifier. The terminals of the by-pass condensers, and the continuity of the wires leading to them, should always be checked when the amplifier action seems at all unstable. There is also the possibility that the open circuit may be inside the condenser, a matter that can be checked as hereafter described.

Loss of Sound in Amplifier

(35) If sound should be lost and the amplifier be suspected, the first step is to determine whether the trouble is actually within the amplifier or not. Thus, in the case of Figure 140, headphones (high resistance phones only) might be connected across the primary of T-1, to be sure the amplifier is being supplied with sound current. If such is the case, the phones are next connected across the secondary of T-3, to determine whether sound current is leaving the amplifier. If sound is heard in the headphones during the first test, but not during the second, there is no question but that the amplifier is at fault.

If sound is not heard during the first test then the trouble is not in the amplifier, but between the amplifier and the photo-electric cell. If sound is heard on both tests then the trouble lies between the amplifier and the loud speakers.

The same test, however, is more difficult in the case of Figure 139. No sound will be heard if the headphones are connected across resistor R-1, because the photo-electric cell output is not strong enough to operate a headset. The phones would have to be connected across resistor R-4, and if no sound is heard there step-by-step examination of all apparatus between that point and the

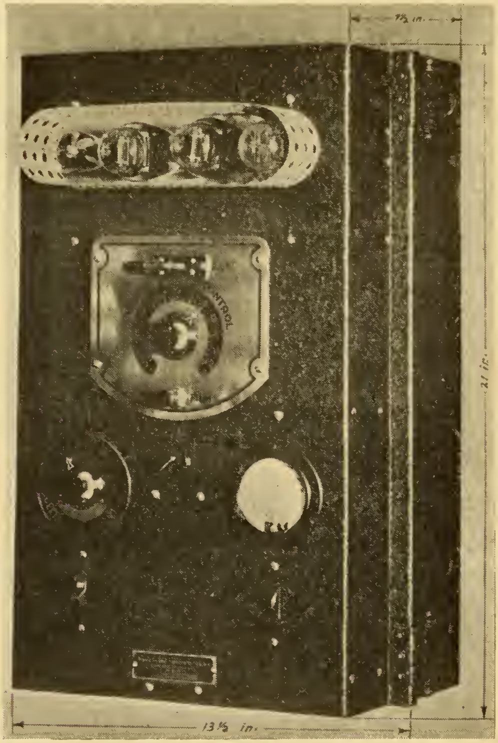


FIG. 142. A medium-sized amplifier made to mount on the front wall between the two projectors.

photo-cell becomes necessary. Such examination would be begun by checking all the voltages of the RCA-57, and the anode voltage to the photo-cell.

The output test for Figure 139 is the same as for Figure 140, namely, headphones across the secondary of the output transformer (T-2) to make sure that the loss of continuity was not between the amplifier and the speakers.

When loss of sound has been definitely traced to the interior of an amplifier the fastest procedure is to determine that all tubes are lit, and then read all available meters. The meters of Figure 140 should reveal almost at once exactly where the trouble lies. There is very little in Figure 140 that can go wrong without affecting the meter readings. Thus, a low meter reading on M-1, which is not improved when the tube is changed, would indicate an open circuit in R-2, R-13, R-14 or their connecting wires, or a partial short-circuit across R-11 or R-12, or C-1. A portable voltmeter will then discover the precise location of the fault in a very few minutes. Figure 139 is not equipped with built-in meters, but a portable tube-meter is likely to repay its cost the very first time trouble occurs. In the absence of such an instrument the best procedure is to continue headphone tests within the amplifier until the area of possible trouble has been so circumscribed that visual inspection will reveal the fault.

Assuming sound has been heard when testing across R-4 of Figure 139, the next test may very well be applied to the primary of T-1. If no sound is heard there, the trouble lies somewhere in the apparatus or supply voltages between those two points. If sound is heard across the primary of T-1, the trouble is somewhere in the apparatus or supply voltages of the last two stages, and the next tests may be applied across the resistors R-11, or the primary of T-2.

Assume that the loss of sound has been traced to some one stage, as, for example, the first RCA-56 in Figure 139. All voltages to that tube should be tested with a tube-meter or a portable voltmeter. If neither is available the headphones can be used for a rough test. Connecting the headphones across the socket terminals will indicate by a click whether or not voltage is present, and it is even possible, with experience, to tell by the loudness of the click if the voltage heard is as high as it should be. If all tube voltages are normal the trouble can only be in some sound circuit in which no tube supply flows, as, for example, an open circuit in Condenser C-6, in coil L-3, or in the primary of T-1. Or the primary of T-1 might have been short-circuited by the grounding of one of its terminals. When the location of the trouble has been brought down, by such tests as these, to an extremely small area, visual inspection and tugging at wires usually gives faster results than further application of test meters or headphones. In such inspection one looks for signs of overheating, melted insulation, or a bad soldered joint, also for some hair-thin strand of wire that may have grounded a sound circuit.

Assuming, on the other hand, that the loss of sound has been traced to some one stage and the tube voltages have been found not normal, then the procedure is to run down the supply line of the abnormal circuit, looking for an open, a short or a ground. This is best done with a portable voltmeter, but it can also be done visually and by tugging wires.

Once trouble within an amplifier has been traced to some single circuit the speed with which it is cleared up is largely a matter of the common sense of the trouble-shooter, and of the extent of his grasp of the simple fundamentals that are common to all electrical circuits.

Loss of sound in an amplifier is not a trouble difficult to find. The chief requirement in finding it, when it occurs during a show, is speed. Speed is secured, first, by glancing at all tubes to make sure that they are lit, and by taking all meter readings. Second, by making sure the trouble is actually within the amplifier, using headphone tests as described. Third, by locating the particular stage or circuit within the amplifier that is at fault, using either meters, portable meters, or headphones, whichever comes fastest. (In the case of Figure 140 the meters make headphone tests almost unnecessary; in the case of Figure 139 the chances are that using the phones will prove faster than resorting to portable meters.) Fourth, detailed examination of the precise circuit or stage found to be at fault. Fifth, in those rare cases where there is no indication of trouble in the circuit

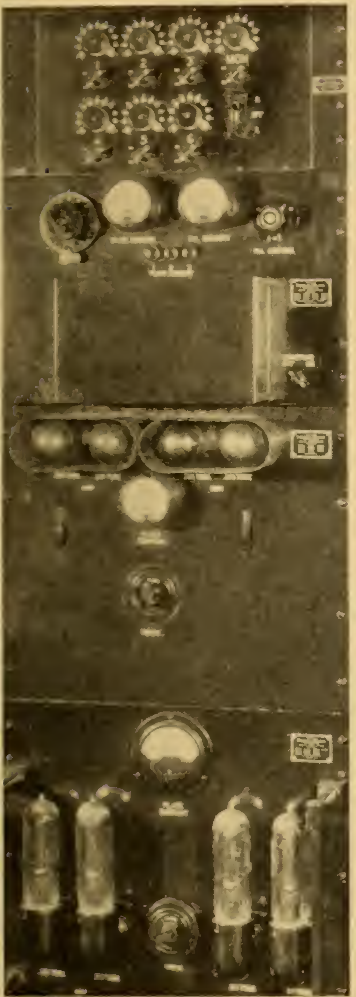


FIG. 143.—Projection room rack mounting three amplifiers and speaker-voice-line control panel.

known to be faulty, it may be necessary to test each piece of apparatus in that circuit individually, with meters, dismounting it if necessary.* This last is an extreme that will hardly ever be reached. (Methods of testing resistors, coils and condensers are given on Pages 660 and 661.)

(36) Low volume from an amplifier is traced in much the same way as complete loss of sound, but is harder to run down. When headphone tests are applied it may prove difficult or impossible to decide whether the volume heard at any one point is normal or not. Much greater reliance must therefore be placed on meter tests. In extreme cases the cause of low volume may not be found in the projection room, and the amplifier may have to be sent back to the factory, where delicate instruments are available. Fortunately, low volume from an amplifier is not a common trouble (except as tubes grow weak, which is a condition readily discovered

* Never use a test buzzer or a trouble lamp to ring through a sound transformer, or through a sound choke such as L-3 in Figure 139, or L-1 in Figure 140. Never use a cheap, low-resistance voltmeter, or cheap, low-resistance headphones, in testing such apparatus or any circuit connected with them. Excessive current through such windings "saturates" (permanently magnetizes) the core, and changes the frequency response of the instrument.

and not to be classified as trouble), while low volume in an amplifier that cannot be traced with meter tests is very rare.

Intermittent loss of volume is a more common and more difficult trouble. The condition is usually created by a make-and-break connection, extremely difficult to find when the break does not last long enough to allow for detailed testing. It is common practice to shake, hit or punch the amplifier in order to make the break permanent, so that tests applied will find it. Connections are tugged and parts rapped or shaken, with the same object. Patience is the chief requirement in tracing this type of amplifier trouble.

Hum and oscillation in an amplifier are commonly traced by looking for probable causes. The most usual causes of such troubles have already been listed and explained at length.

Transmission Line Between Amplifiers

Where more than one amplifier is used the transmission line between them resembles the coupling between tubes inside of one amplifier. Transformer coupling is used almost invariably. Thus the output of Figure 140, through key switch K-1, need not lead to the speakers. The circuit may also terminate at the input transformer of another amplifier. In that case, however, transformer T-3 would be changed for one that would offer a better impedance match to the input circuit of the amplifier following.

Transmission Between Amplifiers and Speakers

The nature of this line varies greatly in accordance with the number and type of speakers used, and can be discussed to better advantage after loud speakers have been studied.

SPEAKERS

1. Explain the construction and operation of a telephone receiver.

THE MAGNETIC TYPE SPEAKER, PAGE 585

2. Explain the construction and operation of a magnetic speaker.
3. Does a magnetic speaker have a "field coil"?

THE DYNAMIC TYPE SPEAKER, PAGE 587

4. Explain the construction and action of a dynamic speaker.
5. What is the field coil? Describe four sources of supply for it.
6. What is the voice, or speech coil?

HORNS AND BAFFLES, PAGE 589

7. Why are horns used?
8. What are "directional baffles" and why are they used?
9. Why are flat baffles used?

INCREASING SPEAKER FREQUENCY RANGE, PAGE 590

10. What are "woofers"?
11. What are "tweeters"?
12. What is a crystal speaker?
13. Why are flexible arrangements necessary in the transmission line to loud speakers?

SPEAKER CARE AND TROUBLES, PAGE 594

14. Name and explain three principal speaker troubles.
15. What precautions are needed in speaker transmission and supply lines?
16. What is meant by "poling" speaker units?

CHAPTER XXIX

SPEAKERS

The simplest form of loud speaker is the common telephone receiver that anyone can open and examine, and almost everyone has. Equipped with a small horn, that instrument can furnish enough sound for a moderate-sized room, and when so used is essentially a magnetic-type loud speaker.

(1) If the reader has ever unscrewed the cap of a telephone receiver he has found underneath a disc, or diaphragm, of thin stiff metal. Under this, again, he found a horseshoe magnet, curved to follow the outline of the instrument, and two coils of very thin wire. The two coils of wire are wound around the poles of the magnet. When current flows through them they produce a magnetic field, which either aids or opposes the permanent field of the horseshoe magnet.

This much being clear, the metal diaphragm may be studied more carefully. When in operating position it is held firmly at its circular edge, while its center is pulled inward by the magnetic attraction. The metal of which the diaphragm is made possesses elasticity, and its center, pulled inward by the magnet, has a natural tendency to spring back toward neutral position whenever the magnetic attraction is lessened. If, on the other hand, the magnetic attraction is increased, the center of the diaphragm is drawn still closer to the pole-pieces.

In an instrument of this construction, a. c. or pulsating d. c., fed to the two coils, will cause the center of the diaphragm to vibrate in accordance with the frequency and strength of the current supplied.

Whenever the diaphragm vibrates it acts upon the surrounding air, pushing that out of the way when it moves outward, and leaving a vacuum into which air promptly rushes, when it moves inward. (See Page 414.) In consequence, the vibrations of any unsteady current supplied to the coils of the receiver are converted, by the receiver action, into similar vibrations in the nearby air, which the ear will apprehend as the sound of words or music.

This instrument, however, is not capable of more than ear-volume unless it is equipped with a horn. Without a horn, high volume merely makes it rattle. The reason is not hard to understand.

When the receiver is operating under normal conditions, without a horn, air pushed out of the way when the diaphragm moves outward is pushed in all directions, and therefore offers comparatively small resistance to the diaphragm's motion. Similarly, when the diaphragm moves inward air rushes from all directions into the vacuum it leaves behind, and there is no very great disparity of air pressure on the two sides of the diaphragm to hinder its free motion. In short, the diaphragm, without a horn, is a motor moving without a load, and it moves easily and freely. If the volume is made high, the diaphragm will strike against the pole pieces each time it moves inward, and thereby add a rattling noise to the sound it creates.

When a horn is added the motion of the diaphragm meets greater resistance, since the neck of the horn confines the surrounding air and limits its freedom of motion. The diaphragm is then a motor operating under load. It moves through a smaller distance but imparts motion to a greater quantity of air, since the air immediately in front of it cannot slip away to either side. Therefore it creates a higher volume of sound (imparts greater energy to the air) without moving far enough to strike against its pole-pieces. In just the same way a motor running at high speed without load may wreck itself in doing less work than it would running safely at low speed with a full load.

The Magnetic Loud Speaker

(2) Magnetic loud speakers are used in theatres as

monitors. The monitor in Figure 139 is a magnetic speaker, as shown by the crescent-shaped magnet placed just left of the winding. Magnetic speakers that are essentially only large telephone receivers equipped with long "lily" horns have been used in some theatres to increase the audibility of the vaudeville performance. The speakers are scattered throughout the house, especially in the upper balcony, where the sound of vaudeville is most likely to need reinforcement. This method, however, is not typical of modern "reinforcement" practice, which is outlined briefly on Page 529.

The commonest type of magnetic speaker, and the type most often used for monitor work in the projection room, does not have a horn, but a "cone," which is a diaphragm from six to twelve inches across, usually made of paper. The magnetic fields of course cannot operate directly on a paper diaphragm. An armature is provided, consisting of a small bar of metal pivoted to respond to the fluctuating magnetic field, and connecting with the center of the diaphragm through a tiny lever. The elasticity of the paper cone pulls the armature away from the center of magnetic attraction, thus opposing the pull of the magnets. When the magnetic pull increases the center of the cone is drawn inward, and when the magnetic pull relaxes the elasticity of the cone causes its center to rebound outwards.

This arrangement needs no horn to provide a load for the diaphragm, since the area of the cone is large enough to act upon a sizeable body of air. At extreme volume magnetic speakers of this type will rattle, because the small metal armature will touch the pole-pieces if it moves far enough, but even a small speaker of this kind can produce sufficient volume for an average projection room before the point of rattling is reached.

(3) Magnetic speakers usually have two coils of wire, as most telephone receivers have (some have been made with three) but these coils are speech or voice coils. There is no field coil in a magnetic speaker, because its primary field is provided by a permanent magnet. The function

of the voice coil is, as explained, solely to oppose or to reinforce that field.

(4) The dynamic speaker is made to produce sound at high volume, and in consequence its diaphragm or armature must move through a relatively great distance, even when loaded by a horn or a cone of large diameter. Manufacturers have not found it practical to provide a permanent steel magnet of such strength that it will continue to exercise an even influence upon the moving diaphragm over appreciably wide distances. Instead, an electro-magnet is used for speakers intended to reproduce sound at high volume. The winding of the electro-magnet so used is the "field coil" of the dynamic speaker.

The voice coil of the same speaker commonly consists of a very few turns of wire, firmly fixed to the diaphragm. Alternating current is supplied to this coil through the output transformer of an amplifier. The voice coil therefore produces an alternating magnetic field, while the field coil, being supplied with d c., possesses a steady field. During every cycle of alternating current that flows through its windings, the voice coil will be alternately attracted toward and repelled by the magnetic field of the electro-magnet. Hence the voice coil, and the diaphragm attached to it, will vibrate around the central, or neutral, position which they normally occupy by virtue of the mounting and inherent elasticity of the diaphragm. The extent and frequency of their vibration will be governed (since the field of electro-magnet does not fluctuate) solely by the amperage and frequency of the voice coil current.

(5) The field coil, which is the winding of the electro-magnet of a dynamic speaker, must be powered with relatively smooth d. c. If a. c. were used a powerful 60-cycle hum would be heard. If rough or pulsating d. c were used the pulsations would be heard in the sound. Perfectly smooth d. c. is not necessary, partly because the field coil of any speaker makes a very good filter choke, and partly because irregularities in the speaker field supply are not amplified (while irregularities in the d. c. supply to a photo-cell, for example, are amplified tremen-

dously). Moderately smooth d. c. is all that is required for speaker fields, and such current can be obtained from any of a number of convenient sources.

We saw in Figure 139 that the field winding of a loud speaker could be made to do double duty by acting also as a filter choke in the output circuit of an amplifier's rectifier. This method of powering the speaker avoids the necessity for a separate source of d. c. and saves the cost of an additional part for the filter. This is the most modern method of providing speaker field supply, and is used in nearly all the more economically-priced systems.

A second method, one of the earliest used, is to power the field coil by means of a bank of storage batteries.

A third procedure, very widely followed, is to use either line d. c., or, where only a. c. lines are available, the d. c. output of the arc generator or rectifier. This method of power supply usually requires a resistance to reduce the d. c. voltage to the voltage needed. To make the power loss in that resistance as small as possible speaker fields are often wired in series. The resistance commonly takes the form of a rheostat, which can be adjusted to compensate for voltage variations in the supply source. Such a rheostat, together with an ammeter that is consulted in adjusting it, is often mounted in a metal box, the entire assembly being called a "horn field control cabinet," or by some similar name. Switches are usually provided backstage, by means of which any speaker field that may open-circuit can be shorted out at once; otherwise a break in one field winding of the series circuit would stop the show until the faulty unit had been replaced. The horn field control cabinet, mounted in the projection room, contains a similar switch to guard against open-circuit in the monitor.

A fourth method of powering speakers is by use of rectifiers which may be either of tube or of disc type. The combination vacuum tube rectifier of Figure 115 has an output circuit (lower left) for speaker field supply. Individual rectifiers are also used for the purpose. In some cases these are mounted backstage, and are under care of the stage crew rather than of the projectionists.

(6) The voice coil (speech coil, speech winding) of the dynamic speaker is of course powered by the output of the amplifier (Figure 139). It consists of comparatively few turns of wire rigidly attached to the diaphragm. It carries no core of its own, but in many speakers it moves in a slot, gap or recess provided for it in the core of the field winding.

(7) Horns are used with dynamic speakers for two reasons. One is to "load" the unit when the diaphragm is of small diameter, as explained above in connection with magnetic speakers. The other is to provide a directional characteristic, which helps in securing equal and accurate distribution of sound throughout the auditorium.

(8) The directional baffle differs from the horn principally in that it is intended to load a larger diaphragm. The neck of the directional baffle is therefore not as small as the neck of a horn, but in other respects the instrument looks enough like a horn to be mistaken for one. It helps in obtaining even distribution of sound in a large theatre. .

(9) Flat baffles are used with the larger diaphragms to obtain good reproduction of the lowest frequencies. All sound can be heard around a corner, out of sight of its source, but low-frequency sound is exceptionally non-directional. When the speaker diaphragm moves forward it creates an area of compressed air in front of it and an area of rarefied air behind it. If the sound is of low frequency the compressed air will ooze right around the edge of the speaker into the region of rarefied air. Compression and rarefaction will cancel each other, and the low frequency sound will be lost. Cone-type speakers not equipped with horns or baffles nearly always sound "tinny" because of this loss of low frequencies. Such speakers are "baffled" by mounting them against a circular hole cut into a flat board of sufficient area. This conserves the low frequencies; it also helps to load the diaphragm, inasmuch as the air being moved, while it can slip sidewise, cannot slip backward into the area of rarefaction. The dimensions of the baffle are governed by the lowest frequency desired. The lower the fre-

quency, the greater the area of the baffle must be. Three cone-type, low-frequency speakers are shown mounted against the bottom of a flat baffle in Figure 144.

INCREASING FREQUENCY RANGE

Figure 144 is a picture arranged to explain one type of multiple speaker installation designed to cover an unusually wide range of frequencies. The large horns at the top of that picture are capable, when used alone, of providing sound of all frequencies between about 60 and 6,000 cycles. This represents the highest standard of theatre reproduction obtainable a few years ago. The white dashed line on the right-hand speaker shows the axis or center of the sound beam emitted. The fact that the center of the sound beam is not the center of the horn must be taken into consideration when the position of this horn is adjusted to secure the best distribution of sound in the theatre. The dynamic unit is shown mounted, face downward, to the neck of the right-hand horn.

(10) When used as in Figure 144 the large horns are wired (see Page 593) to receive and reproduce only frequencies between 300 and 3,000 cycles. Sounds ranging from 50 to 300 cycles are reproduced by the three low-frequency speakers, called "woofers," which are seen at the bottom of the baffle. The stage itself forms a continuation of the baffle.

(11) Near the top of the baffle board are the two high-frequency speakers, called "tweeters," which reproduce the range between 3,000 and 8,000 cycles. There is less than a foot of baffle above the tweeters. That is enough for them, although it would not be nearly enough for the woofers. The area of baffling required grows less as the frequency becomes higher.

The tweeters shown in Figure 144 are small dynamic speakers equipped with short exponential horns. (The word exponential refers to a mathematical formula for horn design.)

(12) Tweeters of similar appearance are sometimes of the crystal type, neither magnetic nor dynamic, and

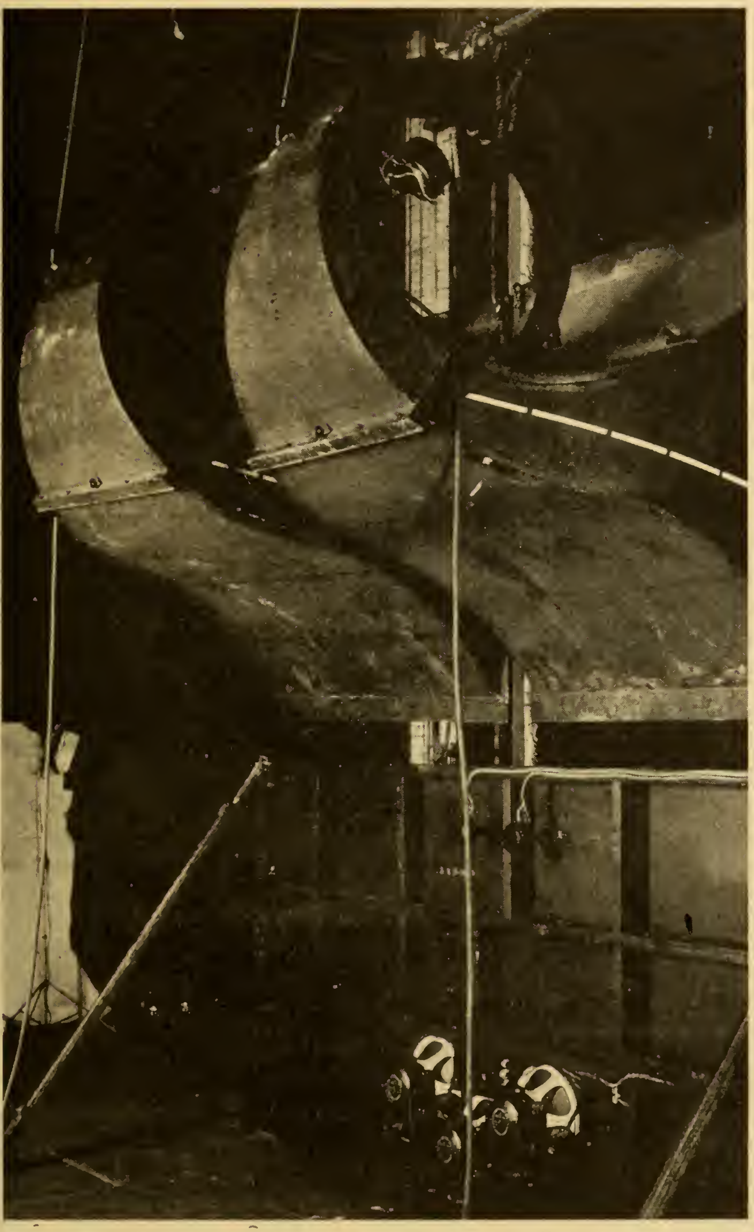


FIG. 144.—A "Wide Range" speaker installation. Compare Fig. 152.

containing no coils at all. They use a crystal of Rochelle Salt (see Page 526) which twists when current is applied to it. The twisting motion of the crystal occurs at the frequency of the current causing it, and is proportional to the strength of that current. They need no field excitation, having no field coils, and being of very high impedance they do not disturb the impedance match between the low impedance speech coils of the larger speakers and a low impedance output transformer, when they are connected directly across the transmission line.

The arrangement shown in Figure 144 is not the only one used to reproduce a wide band of frequencies. Some manufacturers use a single cone-type dynamic speaker so designed that it is capable of reproducing a very wide range of sound. Still another speaker arrangement is pictured in Figure 152.

(13) The transmission line between the amplifier output and the loud speakers is commonly arranged to allow for a variable number of speakers, according to the shape and other requirements of the auditorium. In addition, provision is often made for separate volume control for each individual speaker, which assists in securing the best possible distribution.

Amplifier output transformers are often equipped with tapped secondary coils. By making connection to different taps along a coil of this kind impedance match can be secured to any reasonable number of speaker units. A somewhat different arrangement is pictured in Figure 143. The top panel in that picture (the one with the two rows of tap switches) is a "horn control panel," which must not be confused with a "horn field control panel" (Page 588). The panel in Figure 143 is in the horn speech circuit. It contains an autotransformer, the secondary of which is provided with seven sets of taps. One speaker is connected to each set of taps. The panel thus provides individual volume control for each speaker (by adjusting its tap switch), while overall impedance match between the amplifier output transformer and any number of speakers up to seven (including monitor) is obtained by choosing a correct combination of switch settings.

A suitable combination is found with the help of the following code:

Dial Setting	*Impedance Index*	*Ohmic Resistance*
0	1.	15.
2	.63	9.45
4	.40	6.
6	.25	3.75
8	.16	2.40
10	.10	1.5
12	.06	.9
14	.04	.6
16	.03	.45
18	.02	.3
20	.01	.15

Disregarding the "ohmic resistance" column, which is added merely for information, the code is operated by adding up the impedance indices for all the dial settings chosen. Perfect impedance match is secured when the impedance indices total 1, but any total between .75 and 1.25 will give reasonably satisfactory results. Thus, if there are four speaker units backstage, they may all be set at "6," which with "10" for the monitor would give 1.10, a satisfactory figure. However, if considerations of correct distribution require two of the stage speakers to be operated at higher volume than the other two, a setting of 4-4-10-10-, with anything less than 6 for the monitor, will also serve. A very wide combination of settings, capable of meeting any distribution problem without destroying impedance match, is offered by this panel.

Most speaker transmission lines, however, have much less complicated arrangements, except in the case of such speaker systems as are shown in Figure 144.

With the set-up of Figure 144 the transmission line includes frequency band separators, partly to provide individual volume control of each band of frequencies, and partly to avoid "peak" volume at those frequencies where the speaker ranges overlap. The control of frequency response thus obtainable is very similar in its results, although not in the method followed, to the control given by condensers C-2, C-4 and C-7 in Figure

139, where only a single speaker is used for all frequencies.

Another method of controlling frequency response is to use a number of speaker units of the same type, or of similar type, in contrast to the different types shown in Figure 144, but to provide these units with baffles of special and sometimes complicated construction, each baffle reproducing only a selected range of sound.

Troubles in Speaker Units

(14) Damage to the voice coil, to the diaphragm or to the speech coil may either impair the quality of sound obtained from a speaker, or render it entirely inoperative.

The voice coil may burn out, but this trouble is not very common. However, prolonged and excessive volume, especially at low frequencies, may cause it. Open circuit in a voice coil is rather more likely to be caused by a break at the point where flexible leads are joined to it. The continuous vibration of the coil may break that connection. In some makes of speakers a break at that point can be re-soldered, in some it cannot. In some the construction of the leads is such as to make a break of that kind impossible.

It is a peculiar and interesting fact that in some makes of speakers excessive field current will ruin the voice coil. This has been known to happen where the construction of the unit is such that the voice coil moves in a slot or gap provided for that purpose in the core of the field. Excessive current through the field coil overheats both that coil and its core. When the slot in which the voice coil moves becomes too warm, the cement or glue that holds it to the diaphragm softens and sticks to the sides of the slot, and the coil tears.

The field coil, on the contrary, is commonly wound of heavy wire, little subject to open-circuit, and in a good speaker very seldom gives trouble unless excessive voltage is applied. It is the field coil supply, rather than the winding itself, that needs watching.

The diaphragm, as a moving part subject to great and continuous strain, is the most delicate part of the speaker.

A diaphragm that has become loosened, bent or warped, or that has lost its elasticity, will seriously damage sound quality. It may rattle, or create raspy sound at some one frequency or at high volume. It can seldom be repaired, and in most cases is replaced. Trouble of this kind can usually be heard at once. Where there are several speakers, however, it may be necessary to listen with an ear close to each, until the faulty one is discovered. If two speaker units are mounted on a double-throated horn one must be turned off to trace trouble of this nature.

Transmission Line Troubles

(15) The transmission line can cause bad sound through improper impedance match, as when such tap switches as those shown in Figure 143 are misadjusted. Impedance mis-match will also follow if speakers are replaced carelessly with others of a different make or type. Such replacements may call for changing the output transformer of the amplifier, or a satisfactory adjustment may be made by choosing a suitable speech transformer to be mounted on the speakers themselves, but it is not possible to wire speakers to an amplifier promiscuously and expect satisfactory results.

Stage cables leading to the speakers may prove a serious source of trouble if the stage is used for vaudeville or other entertainment, and the cables subjected to being stepped on. Sooner or later they will resent such treatment and stop a show. Wherever the stage is in use all speaker supply cables should be run overhead.

Pin connectors are sometimes used when speakers have to be moved offstage to make room for a show. These also are a source of possible trouble. Looping the supply cables overhead makes their use unnecessary.

Poling Speakers

(16) Whenever more than one speaker is used it is vitally necessary that all diaphragms move inward and outward in synchronism. If the diaphragms move in opposite directions the sound waves they create will be 180 degrees out of phase and most of the volume will be

lost. Consequently speakers are "poled" or "phased"—that is, connected in the same polarity. Both voice and field lines must be poled. All voice contacts are marked, often with numbers. All the number 1 terminals should be connected to the same side of the output transformer secondary; number 2 terminals to the other side. Sometimes the wires are not numbered, but color-coded. Field coil terminals are commonly polarized + and —, and should be so connected to their power sources.

When speakers of different manufacture are used together reliance on marked terminals may not prevent incorrect poling, and it may be necessary to experiment with reversing polarities to determine which connection gives the best results. When the correct arrangement has been found the speaker terminals and connecting wires should be tagged accordingly.

Whenever a speaker unit is replaced care must be taken to pole the new unit correctly. The connecting wires are tagged for this purpose, and the speaker markings or color code consulted. Of course, where only one stage speaker is used, poling doesn't matter.

On rare occasions a speaker that has been incorrectly poled escapes factory inspection. When such a unit is wired in properly, according to the lettering of its terminals, or to its color code, the resulting loss of volume, especially in the space between the speakers, will reveal the fault at once. To determine which is the winding that was incorrectly marked, reverse connections, first to the voice coil and then, if the change has not increased the volume between speakers, restore the original voice coil connections and reverse those to the field coil. A tag bearing the proper information should then be attached to the speaker, for future reference.

DRIVES

1. What two different classes of mechanism are needed to move the sound film or the disc turntable?

Drive Motors, page 599

2. What is required of a drive motor?
3. What are "wows"? What is "flutter"?
4. What is the most common type of drive motor?
5. Why is it successful?
6. Is a synchronous motor used to drive a non-synchronous turn-table?
7. Are synchronous motors used in theatres where only d.c. is available?

Motor Speed Controls, page 601

8. Name four methods of controlling motor speed.
9. What is centrifugal speed control as used with d.c. motor? Explain how it works.
10. How does motor speed affect the centrifugal contacts?
11. What are "motor control cabinets"?
12. Explain the action of a motor control cabinet that has no tubes.
13. Explain the action of a motor control cabinet using vacuum tubes.
14. What is "hunting" in a motor?

Drive Transmissions, page 617

15. What is the drive transmission?
16. What is required of the drive transmission?
17. What is a "damping device"?

Care and Troubles of Drives, page 620

18. What care do projector motors require?
19. What maintenance is needed by speed control devices? What is the greatest help in tracing their troubles?
20. What attention does the drive transmission need?

CHAPTER XXX

DRIVES

(1) To move the sound film, or the disc turntable, two classes of mechanism are required. One is the driving motor. The other is the transmission, consisting of gears, chains or pulleys, or combinations of all three, by means of which the motion of the motor is conveyed to the disc turntable or to the sprockets that move the film.

It will be logical to postpone discussion of the transmission mechanism until the motors that drive it have been considered.

(2) Four things are required of a modern projector drive motor. (a) It must be sufficiently powerful to perform the work. (b) It must possess moderately strong starting torque (torque is rotary force) in order to bring the projector up to speed promptly and avoid sloppy changeovers. On the other hand, the starting torque must not be so great that the mechanism is started with a jerk that might strip or weaken the teeth of the gears, or tear the film. (c) It must revolve at precisely the same speed as the motor with which the recording was made, neither slower nor faster, otherwise music will be off key and voices out of proper pitch. (d) It must impart an absolutely steady and unwavering speed to the film or record.

Slight fluctuations of motor speed are distinctly audible, and spoil sound completely. Since the pitch of reproduced sound depends entirely on the speed of the motor (Page 486), fluctuation of motor speed will make a steady note sound like a rapid succession of two different notes, one somewhat lower or higher than the other.
(3) If the motor speed fluctuates rapidly this condition is called "flutter." If the change in speed takes place

more slowly, creating a continuous, sighing change of pitch, the condition is called "wows."

To repeat, the four requirements of a good drive motor are:

(a) Sufficient power.
(b) Proper starting torque.
(c) Correct speed.
(d) Absolutely steady, uniform motion.

The special methods that secure these results from electric motors used for sound projection are described in detail in the paragraphs following, but the principles of motor action as such, apart from special means used to secure special results, cannot be discussed here. There are so many different types of electric motor that a book larger than this would be needed to do justice to that subject. Such books are available in any public library. There would be little value in taking a small amount of space from matters pertaining specifically to projection in order to devote it to a sketchy and inadequate account of motors. The fundamentals of motors have already been discussed elsewhere. Here we are concerned only with methods, peculiar to the projection room, that are used to secure exceptionally accurate and steady control of motor speed.

(4) The synchronous motor is the type most widely used for projector drive. The speed of this motor depends entirely upon the frequency of the line that supplies it. Increasing the load to be moved cannot slow down the motor, although it may stop it altogether. The current through its windings has no effect upon its speed, hence its action is independent of line voltage fluctuation. If the line voltage should become too high the motor might conceivably burn out, or if the line voltage should fall too low the motor might stop, but its speed can never vary unless the line frequency changes. The very simple reason for these facts is explained fully in any good book on motors.

(5) Synchronous motors for projector drive have proven successful because power companies regulate their frequency very carefully, even when they allow

their voltage to vary enormously. Frequency regulation is a matter of dollars and cents to a power company. All their generators, line transformers and other apparatus are designed for maximum efficiency at rated frequency, and permitting the frequency to vary means unnecessary losses. Frequency control of power lines has been so improved during the last few years that a frequency-controlled projection motor can be relied upon, in most American theatres, to maintain constant speed at all hours of the day or night.

(6) Synchronous motors are often used to drive the non-synchronous turntables in the projection room. There may seem on the surface to be some confusion at the idea of a synchronous motor driving a non-synchronous turntable. The facts are that the motor is synchronous because it operates in synchronism or resonance with the line frequency, while the turntable is non-synchronous because the sound taken from it is not synchronized with a moving picture.

(7) Synchronous motors are not used where only line d. c. is available. In theatres not equipped with alternating current a converter driven by d. c. can be used to generate alternating current for the operation of an a. c. amplifier. But the frequency of the alternator's output will not be absolutely constant unless its speed of operation is held absolutely constant. Why trouble to regulate the speed of a d. c. motor driving an alternator? It is as easy to regulate the speed of a d. c. motor driving a projector, and a smaller and less expensive alternator can be used.

Synchronous motors are also omitted from the equipment of theatres that show silent pictures occasionally and may wish to vary their projector speed. The speed of a truly synchronous motor cannot be varied.

(8) The use of the synchronous induction motor is only one method of securing proper projector speed. Three other methods of obtaining the same result are in common use. There are "centrifugal" speed governors, used at present only with d. c. motors. There are motor control circuits involving vacuum tubes, used with both

d. c. and a. c. motors; and motor control circuits not involving vacuum tubes that are used with a. c. motors only.

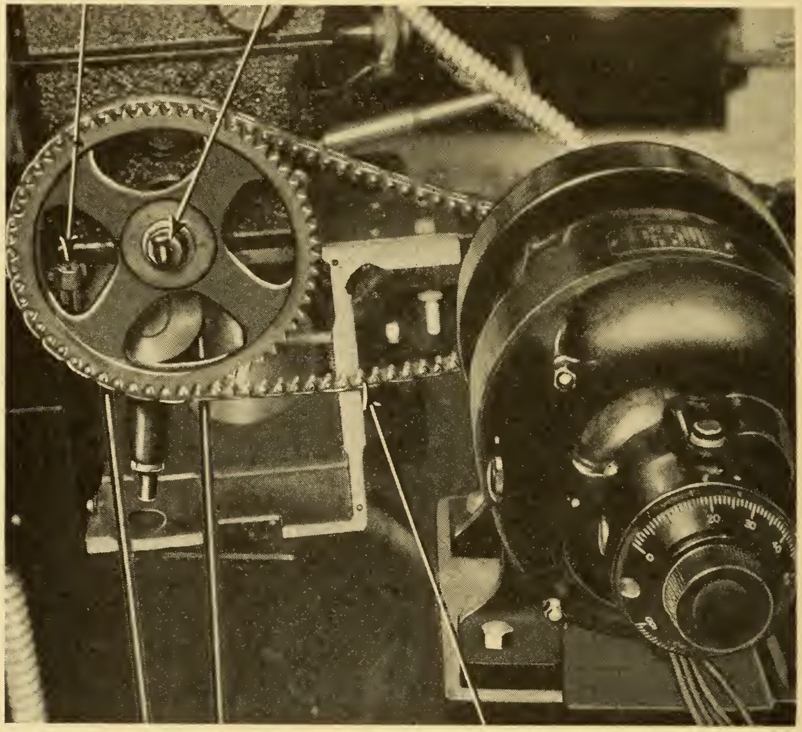


FIG. 145.—Drive using centrifugal speed control.

(9) Figure 145 is a picture of a d. c. motor equipped with centrifugal speed control. Figure 146 is a schematic diagram showing the working of this apparatus, and Figure 147 is a detailed drawing of its mechanical construction.

The operation of this system is explained very clearly by Figure 146. The mechanical action is best studied in Figure 147. The centrifugal force of the motor's rotation (the same force that causes a revolving wheel to throw mud) drives the flyweights of the centrifugal device outward in opposition to the tension of a retaining spring, and compels the center on which they are pivoted to touch the adjustable contact immediately in front of it. Closing this contact (Figure 146) short-circuits a

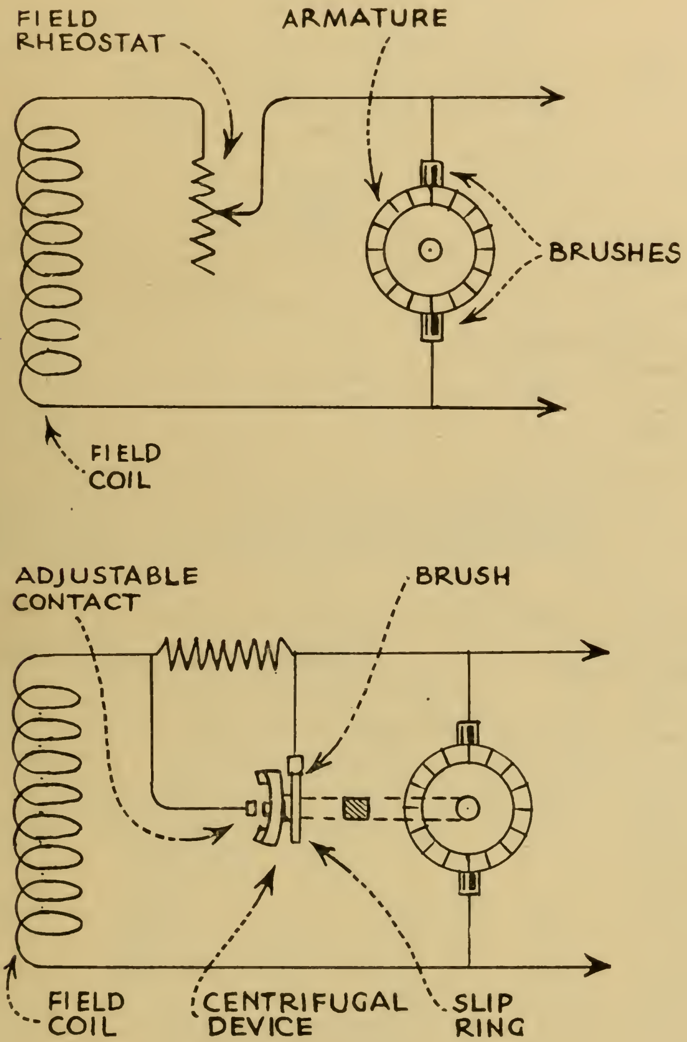


FIG. 146.—Electrical diagram of centrifugal speed control system.

resistance in the motor field line, increasing the current to the motor field.

Any elementary book on motors will explain that when field current is increased a shunt-wound motor slows down, and vice versa. The reason, very briefly, is that a motor always acts as a generator, creating a counter-voltage in its own armature. A stronger field current increases this counter-voltage, reducing the armature current so greatly that the motor runs slower.

(10) It is high speed in the motor of Figure 146 that forces the flyweights outward and closes the centrifugal contact, thereby short-circuiting the field resistance and increasing the field current. Thus, excessive motor speed compels the motor to slow down. Conversely, when the motor speed declines, the centrifugal contact opens, cutting in the field resistance, decreasing the field current and causing the motor to speed up. The action of this contact is a continuous, chattering make-and-break. The rotating parts of the motor are too heavy to permit the motor speed to fluctuate as rapidly as the centrifugal contact opens and closes. In consequence, the motor maintains a steady, average speed, at the rate required by the setting of the adjustable contact. The radio-type dial by which this contact is adjusted is prominent in the foreground of Figure 145.

An additional three-position switch, not shown in these drawings, provides further variation of the motor field current, and therefore greater variation in speed than is attainable by the adjustable contact.

Figures 145, 146 and 147 are so plain that further discussion of this simple method of speed control seems unnecessary.

Motor Control Cabinets

(11) Five types of speed control cabinets, all produced by one manufacturer, are used to regulate projector speed. To some extent they are being superseded by the simple synchronous motor. Many, however, are still in use. The tubeless type is diagrammed in Figure 148.

(12) The dot-dash line of Figure 148 separates the motor from the control box wiring. In this arrangement

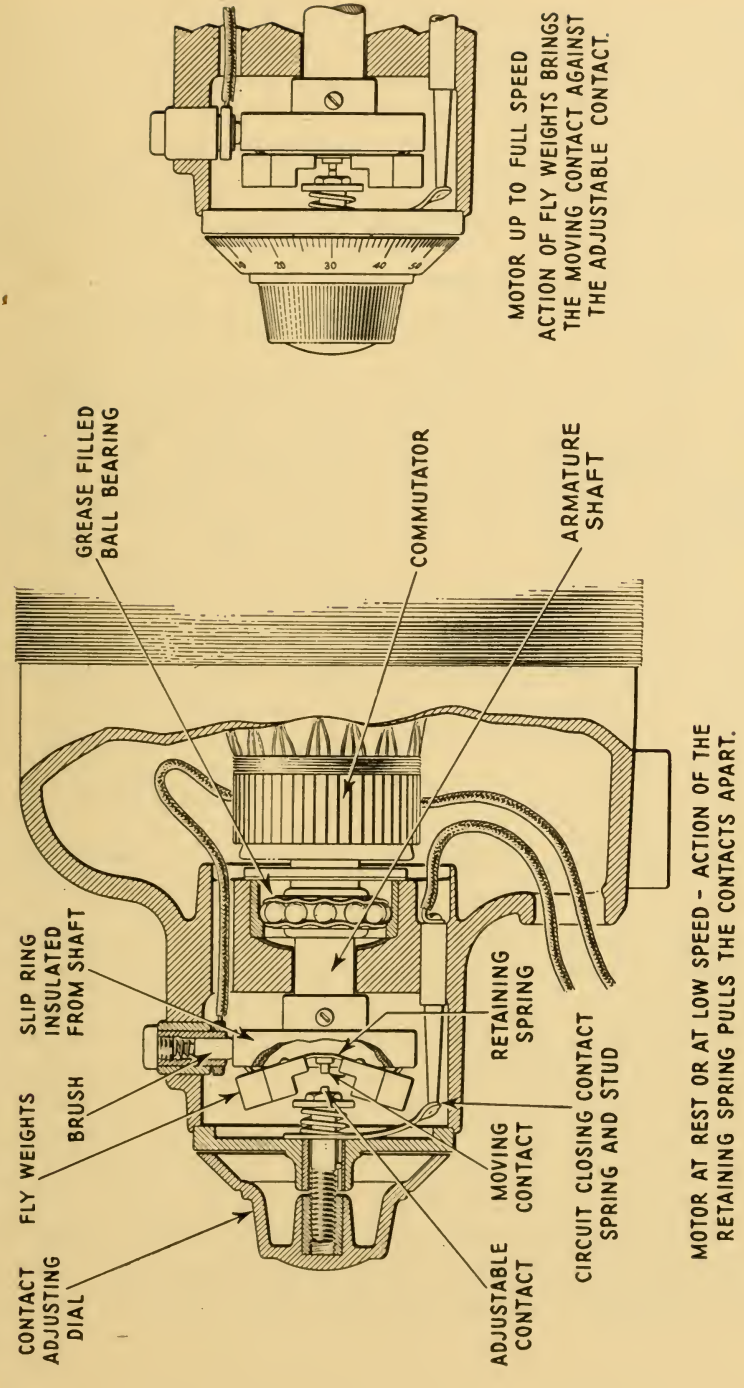


FIG. 147.—Mechanical diagram of centrifugal speed control system.

the speed is regulated primarily by the motor itself and by the induction machine (a. c. generator) mounted on the same shaft. The control cabinet apparatus merely assists in the action.

The motor of Figure 148 contains a stator consisting of the windings designated in the drawing as F-1. The speed control field is composed of windings F-2. Driving

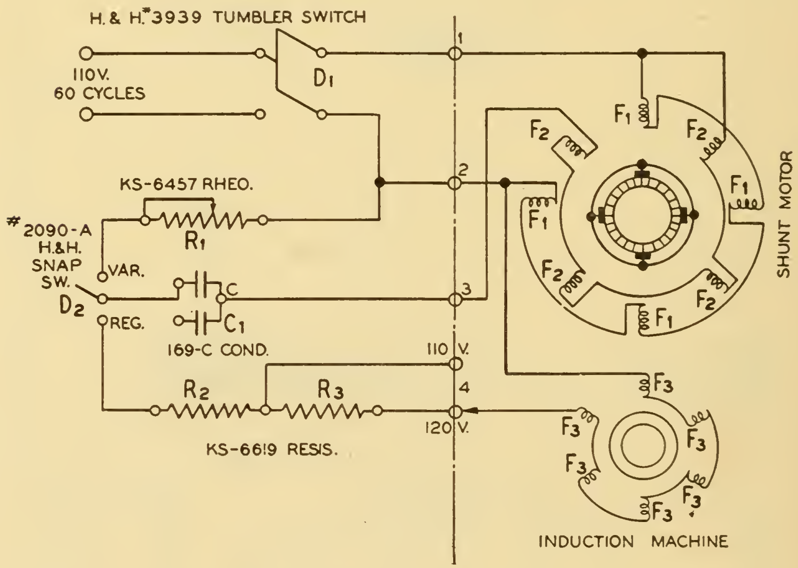


Fig. 148.—Schematic circuit drawing of motor speed control cabinet without vacuum tubes.

current is not led directly into the armature through the brushes. Voltage is induced in the armature by the a. c. flowing in F-1. The four short-circuited brushes shown in the drawing close the armature circuits and permit current to flow in the armature coils.

When Switch D-2 of the control cabinet (left center of the drawing) is thrown to "Regulate" the induction machine is connected in series with F-2 through R-2 and R-3, and the large condenser, C-1. If the motor runs too fast the current generated by the induction machine reinforces the current through F-2, causing the motor speed to decline. When the motor runs slow the current developed in F-3 opposes that in F-2. Additional regulation is secured by the fact that the induction machine is designed for the rated speed of 1200 R. P. M., and imposes a minimum mechanical load on the motor when it is driven at that speed.

Condenser C-1 serves to keep the current through F-2 in phase with the current induced in the armature. Without it the motor could not develop normal power. The additional condenser is sometimes connected in parallel to increase the starting torque of this motor. The contact marked "110 V.," which shorts out resistor R-3, is sometimes used for the same purpose.

When the switch D-2 is thrown to "Variable" the induction machine is open-circuited and does not function. Rheostat R-1 is then used like the field resistor of any shunt motor to vary the speed as desired.

The Circuit of Figure 149

(13) Figure 149 represents one of four types of motor control cabinets using vacuum tubes. This particular model was chosen as an example of such equipment because it is the one most widely used.

The motor is diagrammed at the extreme left. There are three stationary windings, the stator, the field and the armature. The rotating element consists of two parts, namely, the rotor and the toothed iron wheel drawn just above it. The entire arrangement, taken as a whole, may be regarded not only as a driving motor but as a motor-generator assembly consisting of one motor and two generators. One of the generators is an apparatus electrically independent of the motor, although built into the same casing. This is an inductor generator, consisting of the toothed iron wheel, the field coil and the armature coil. The other generator is the rotating element of the motor itself, the rotor. The stator is the driving field. It induces alternating current in the rotor windings, and by the magnetic reaction between the rotor field and the stator field the motor is compelled to revolve.

Let us next see how the stator winding is powered, and how the field of the inductor generator is excited.

The stator is supplied with a. c. from a 110-volt line through the tumbler switch D-1 in the lower left-hand corner of the control cabinet drawing. (In physical fact this switch is located conveniently at the top of the cabinet.) The same switch also supplies line a. c. to the primary of the control cabinet's power transformer, T-1, to which we shall return in a moment. The power supply to the inductor generator cannot be fully understood until the construction of that machine is explained.

The inductor generator consists of two coils, the field and the armature, both wound on iron. The field coil is excited by direct current which is provided by a rectifier tube inside the control cabinet (tube V-3). As the iron wheel revolves with the rotor its projections pass through a gap left for that purpose in the core of the field winding. The magnetic flux of the field winding is thus made to vary in strength, and an alternating current is generated in the stationary armature. The frequency of the armature current is governed by the rapidity with which the iron teeth replace each other in the gap of the field core, and therefore by the speed of the motor. At the rated speed of 1200 r. p. m., the armature frequency is 720 cycles.

We have therefore two a. c. generators in this machine, one being the armature just mentioned, and the other the rotor.

The alternating current generated in the rotor completes its circuit through the rotor brushes and the choke coil L-2 inside the control cabinet, just left of the milliammeter.

Coil L-2 is therefore the "load" upon the rotor, exactly as an arc lamp and its ballast resistor constitute the "load" on the d. c. output of an arc supply generator. The arc generator, however, is compounded to maintain constant speed under variations of load. The motor of Figure 149 is so designed that its speed is very sensitive to changes in the rotor load. Any change in the impedance of L-2 will vary the speed of this motor.

The 720-cycle current generated in the armature acts through the circuits of this cabinet to control the inductance of L-2, and hence to control the motor speed.

The analysis of those internal circuits will unfortunately make somewhat hard reading. There is no help for that, no matter what pains are taken to make the account clear and simple. These particular vacuum tube circuits are altogether different from those we have previously traced in amplifying equipment. We will now have to encounter positive grid bias, grid-controlled rectifiers, and other strange animals. All resting, of course, on the same electrical fundamentals, but still perhaps a trifle confusing in their newness. If the reader will carefully refuse to let himself feel puzzled, remembering that if he understands the elements of electricity and of vacuum tube action he *must* be able to understand these circuits, he should find the paragraphs that follow much easier to digest.

The Impedance of Coil L-2

L-2 is wound on an iron core (not shown in the drawing). The same core also carries the coil drawn just above L-2 at right angles with it. We shall call this second winding the control coil. The two together, with their core, make up the retard coil, 144-A.

Direct current provided by the full wave rectifier (tubes V-1 and V-2) flows through the control coil, creating a magnetic field that very nearly saturates the iron core on which it is wound. The impedance of L-2 depends upon the degree of saturation of that core. A fully saturated magnetic core cannot absorb an additional field (cannot be magnetized further). If this core were completely saturated the impedance of L-2 would be comparatively small. An increase in the direct current through the control coil increases the saturation of the core, reduces the impedance of L-2, and permits the rotor to speed up. Conversely, a decrease in the direct current through the control coil raises the impedance of L-2 and compels the motor to slow down.

The 720-cycle current generated in the inductor arma-

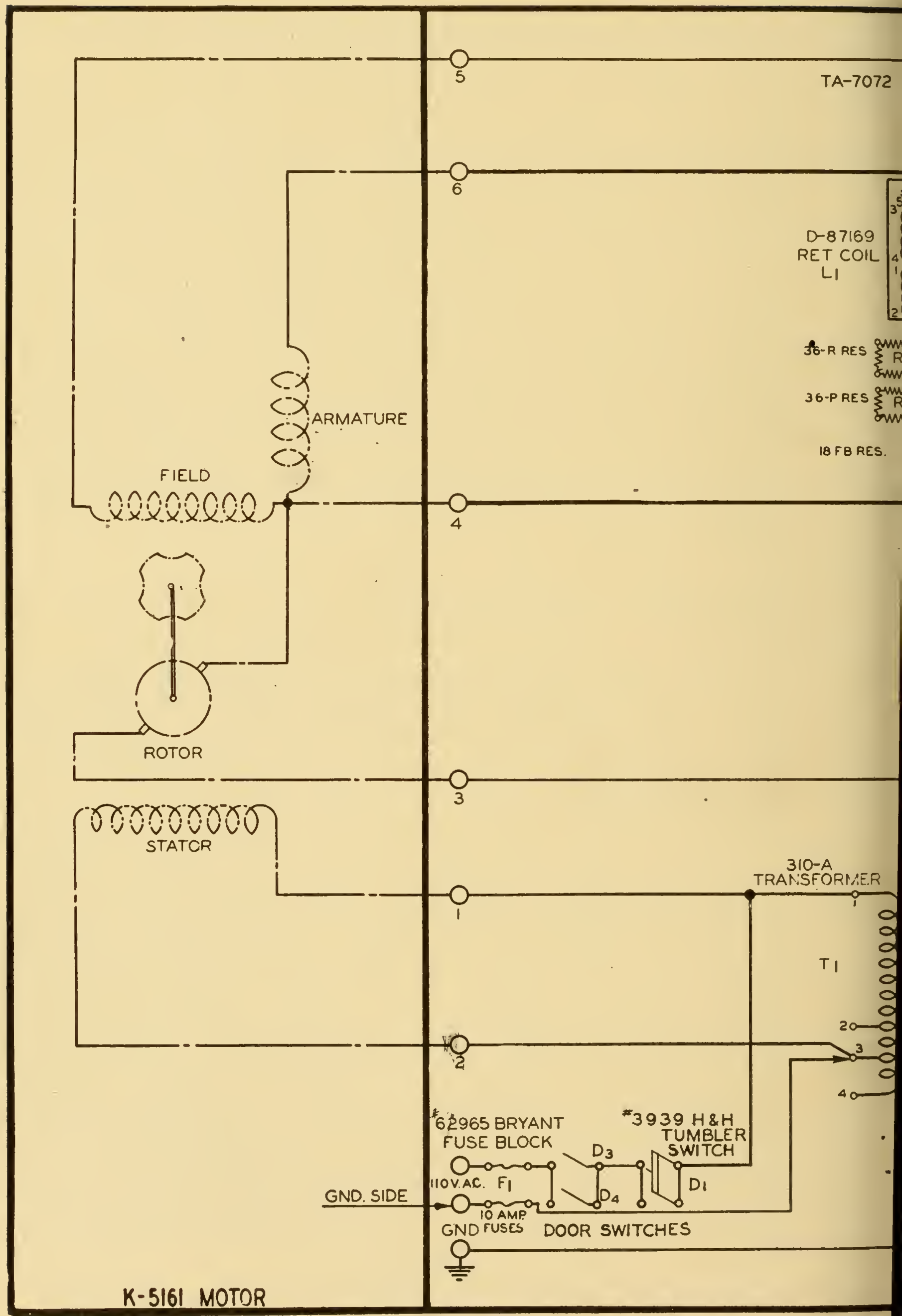
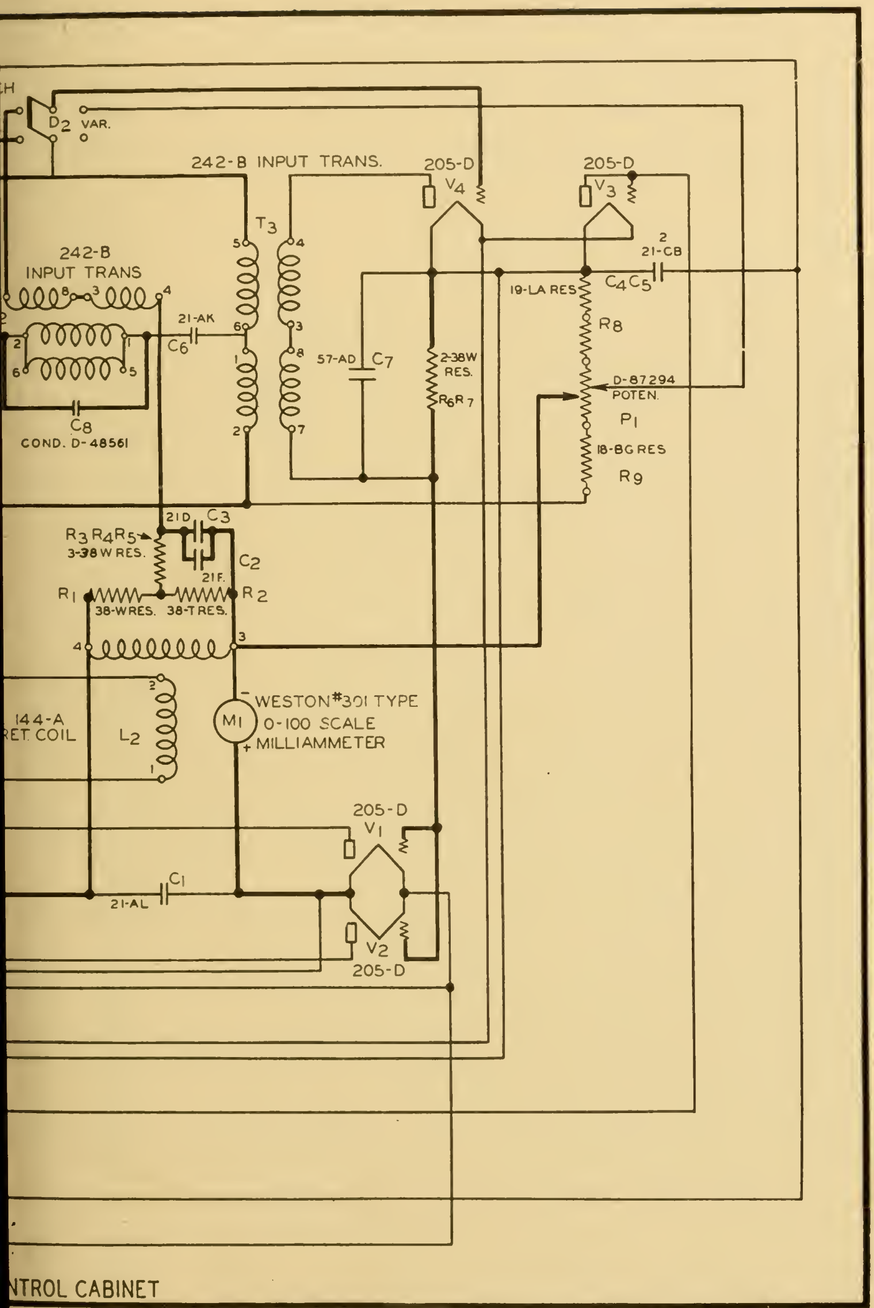


FIG. 149.—Schematic circuit drawing of



d control cabinet using vacuum tubes.

ture therefore operates through the circuits of this cabinet to adjust the amount of direct current delivered to the control coil by the full-wave rectifier, V-1 and V-2. The next step in seeing how this is done is to study that rectifier circuit. It differs in important details from rectifiers we have seen before.

The Circuits of V-1 and V-2

The filaments of V-1 and V-2 are heated by the second secondary from the top, in power transformer, T-1. The plates are powered by the uppermost secondary of that transformer. The positive leg of the output connects to the filaments, the negative side of the circuit returning to the center-tap of the plate transformer. The output of this rectifier flows through the control coil just above L-2. There is a branch circuit through resistors R-1 and R-2, just above the control coil. Condenser C-1 (below L-2) is a filter that keeps the current through the control coil steady.

The unusual feature of this circuit lies in the grids of the two tubes. They control the current flowing through the vacuum, and therefore govern the saturation of the core of L-2 and hence the speed of the motor. Grid-controlled rectifiers of immense size are sometimes used in power houses, but are strange to projection rooms aside from these control cabinets. The grids of V-1 and V-2 carry a positive bias. Negatrons are attracted to them, and there is a flow of current through the external circuits connecting grid and filament. However, the positive charge of the grid is much less than that of the plate, and only a comparatively small portion of all the negatrons emitted go to the grid. The rest respond to the stronger attraction of the plate. The function of the grid is to deprive the plate of current by attracting some of the negatrons. The reading of the milliammeter M-1 depends upon the positive charge of the grid, that is, upon how many negatrons the grids of V-1 and V-2 are able to attract from the plates of those tubes.

Grid Bias Circuits of V-1, V-2 and V-3

The positive bias of the full-wave rectifier is obtained by means of a voltage drop in the field exciting current that is provided by the half-wave rectifier, V-3. The circuits of this tube are conventional, and need not detain us long. Its filament is heated (in series with the filament of V-4) by the third secondary of the power transformer T-1. The bottom secondary provides plate power for V-3. From the top of that plate secondary the circuit may be traced to the plate of V-3, thence to the filament of that tube, down through R-8 and R-9, left across the drawing and through the field of the induction machine, up and around the edge of the drawing to the bottom of fourth secondary of T-1. There is a voltage drop through R-8 and R-9, which as we have just seen are positive at top and negative at bottom. The grids of V-1 and V-2 connect to the top or positive side of R-8 through resistors R-6 and R-7. The filaments of V-1 and V-2 connect, through the milliammeter and the arrowhead contact, to a more negative point, lower down on R-8 or R-9. The grids of V-1 and V-2 are therefore positive with respect to the filaments of those tubes.

Now the speed of our motor is controlled by the space current through V-1 and V-2, and therefore by the bias of the grids of those tubes. Whenever that motor departs from proper speed the alternating current generated in the induction machine armature will become either more or less than 720 cycles, and an appropriate correction must be applied to the grids of V-1 and V-2. This is done by a change in the voltage drop through R-6 and R-7, which voltage drop is in series with the source of grid bias through V-1 and V-2. Therefore, the object of the 720-cycle a. c. developed in the armature of the inductor is to control the direct current through R-6 and R-7, since the drop across these resistors depends upon the amperage flowing through them (Ohm's Law).

The Circuits of V-4

The filament of V-4 is lit in series with that of V-3, the source of power being the third secondary of power transformer T-1. The plate is powered with 720-cycle a. c. provided by the secondary of transformer T-3. The primary of that transformer is excited by the 720-cycle output of the stationary armature. Current can flow in the secondary of T-3 only while the plate of V-4 is positive. Therefore the tube acts as a rectifier, and the rectified d. c. of its output completes its circuit through R-6 and R-7, where it creates a voltage drop that opposes and reduces the positive bias of the grids of V-1 and V-2. The upper, or positive end of R-6 and R-7 connects to the filaments of V-1 and V-2 as follows: upward, right, down through R-8 to the left-hand arrowhead, and thence down, left and down through the milliammeter. Condenser C-7 acts as a filter to steady the d. c. through R-6 and R-7.

The flow of space current in V-4 therefore controls the speed of our motor, and V-4 is a grid controlled half-wave rectifier.

The Grid Bias of V-4

The bias of V-4's grid can be traced backward from that grid as follows: left to switch D-2 (which we now assume is closed at "Regulate"), down and right through the secondary of the 242-B input transformer, and thence downward through R-3, R-4 and R-5 to the left-hand or negative side of R-2. Right through R-2 down, right, and up to the arrowhead touching the lower or negative side of R-8. Up through R-8 and left to the filament of V-4.

We have now progressed to the point where we see that the speed of our projector motor is controlled by the grid voltage of V-4. Before going further we may review briefly, as follows: The grid voltage of V-4 controls the space current of that tube. The space current of V-4 determines the extent of the voltage drop through R-6 and R-7. The voltage drop through R-6 and R-7 is in series with, and modifies, the bias of V-1 and V-2. (That bias is obtained from the plate circuit of V-3, through the voltage drop across R-8 and R-9.)

The bias of V-1 and V-2 rectifiers controls the space current through those tubes, and that space current controls the saturation of the core of the rotor loading coil, L-2. The saturation of the core of L-2 determines the impedance of that coil, and the impedance of L-2 governs the amount of work the rotor must do in turning over, and hence its speed of rotation.

We must now look to see what the 720-cycle current generated in the stationary armature does to the grid bias of V-4.

Wheatstone Bridge Circuit

The 720-cycle output of the armature is given two parallel paths through which to complete its circuit. One is the primary of T-3, which is divided at its center into two halves. The other path consists of the retard coil L-1 and its built-in condenser, plus the resistors R-13, R-14 and R-11. The resistors constitute the lower half of that path, and the coil with its condenser the upper half. The double primary of transformer T-2 bridges across between these two paths. This arrangement closely resembles the classical electrical circuit known as a Wheatstone Bridge.

Coil L-1 and its condenser constitute a filter circuit tuned to 720 cycles. When switch D-2 is thrown to "Regulate" and the output of the armature is precisely 720 cycles, the impedances of the two parallel paths just described are precisely equal. Equal current flows through each, and the voltage drop through the filter matches exactly the voltage drop through the upper half of T-3 primary. Under these circumstances there is no difference of potential across the bridging circuit (the primary of T-2), no current flows across the bridge, none is induced in the secondary of T-2, the grid bias of V-4 is not altered, and the motor speed does not change.

Consider conditions when this motor has just started and is coming up to speed. The armature output is less than 720 cycles. The bridge is unbalanced, current flowing through the bridging circuit. By virtue of the phase-effect of the small condenser in L-1, plus that of C-6 (which two condensers are under those circumstances in series) the current through T-2 primary is 180° out of phase with that in the primary of T-3. The drawing does not show it, but these primaries are so poled that in such case their secondary voltages will be *in phase*. The grid of V-4 will then become more positive (less negative) at the same time that the plate of V-4 becomes positive, which is the only time space current flows. Therefore:

Space current through V-4 increases.
Voltage drop through R-6 and R-7 increases.
Grid bias of V-1 and V-2 becomes less positive.
Plate current of V-1 and V-2 increases.
Saturation of the core of L-2 increases.
Impedance of L-2 declines.
Motor can speed up.

When the motor reaches a speed of 1200 r. p. m. the arms of the Wheatstone circuit are balanced and no current flows across the bridge.

If the motor speed then increases to exceed 1200 r. p. m., generating more than 720 cycles in the stationary armature, the train of events just traced is reversed. Current then crosses the bridge, but by virtue of the inductance of the coil in L-1 it would lag 90° behind the current in T-3 primary, except for the action of condenser C-6, which neutralizes this effect and keeps the current in T-2 primary in phase with that of T-3 primary. By virtue of the poling of these transformers, as just mentioned, their secondary voltages are therefore 180 degrees out of phase. Therefore the grid of V-4 becomes more negative while the plate of that tube is positive, and:

V-4 space current declines.
The drop across R-6 and R-7 becomes less.
The positive bias of V-1 and V-2 is less strongly counteracted.
Plate current of V-1 and V-2 becomes less.
Saturation of the core of L-2 declines.
Impedance of L-2 increases.
Motor slows down.

For the operation of this cabinet when switch D-2 is set at "Variable" see Page 621.

Three variations of the circuit of Figure 149 are in use today. The reader who has understood the foregoing should be able to trace out their action, if he ever has occasion to deal with them, by a study of the schematic circuits pasted inside their covers.

It is the d. c. system that differs most from that of Figure 149. The 720-cycle alternator is essentially the same, but the motor is a d. c. compound-wound machine, with an additional regulating field. There is no rotor output and no coil L-2. The output of the full-wave grid-controlled rectifier that corresponds to V-1 and V-2 of Figure 149 simply flows through the regulating field of the d. c. motor. The arrangement is therefore much simpler than that which we have just studied.

The action of these cabinets governs motor speed with extreme accuracy. In Figure 149 condensers C-1, C-2, C-3, C-4, C-5 and C-7 all act as steadying influences to smooth rough rectified d. c., or to prevent sudden surges in a. c. lines, and thereby counteract the least tendency toward "hunting" in the motor action. (14) "Hunting" is a small variation in motor speed which creates flutter in the sound when it occurs rapidly, or wows if the variation is more gradual. Thus in addition to acting as speed controls these boxes perform, in a sense, the function of flywheels.

Drive Transmission

(15) After the motor is running perfectly, at precisely proper speed and with little or no hunting, it is still necessary to apply the mechanical power created to moving celluloid film or rotating a disc turntable. This is done through the drive transmission.

Transmission methods vary enormously. There are more methods than there are makes of sound systems, since most manufacturers have or have had two or three at least, and perhaps a dozen. However, the action of a mechanical transmission system is not invisible like that of an electric circuit. The projectionist can always see and touch the gears or pulleys of any drive he may ever have to do with, and determine by easy personal observation exactly how it works.

(16) A good transmission system will be noiseless in operation, long-wearing, easy to lubricate and simple to repair. But the first thing required of it is that it shall impart faultlessly smooth motion to the drive sprockets

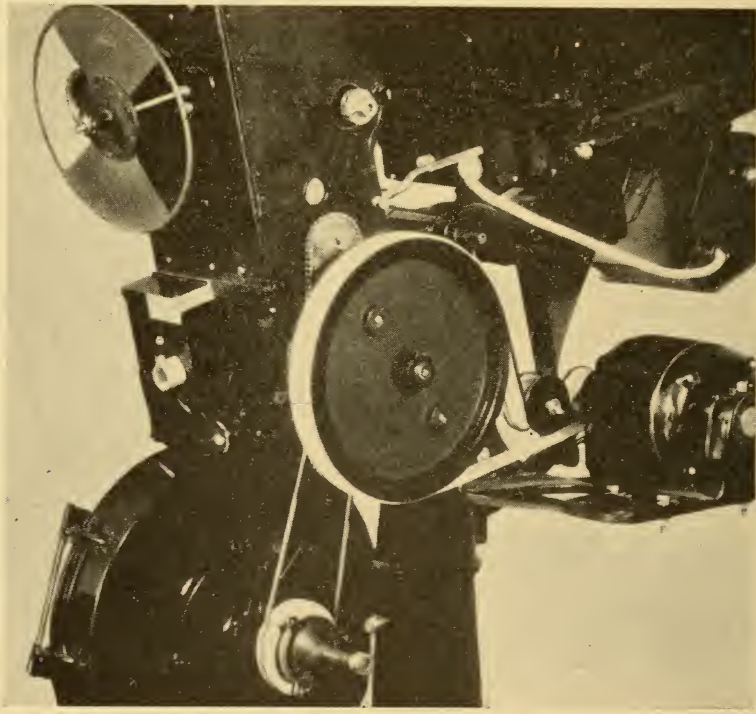


Fig. 150.—Drive side of projector and sound attachment.

of a projector or to the platter of a disc turntable. The transmission must add no irregularities to the motion it receives from the motor. On the contrary, transmission systems commonly include (17) damping devices, or mechanical filters, to counteract even slight vibration in the motor action.

One damping device is pictured in Figures 150 and 151. The former shows a projector, with a frequency-controlled synchronous motor, and belt connection to the mechanical transmission. Two small studs protrude through the large pulley at either side of the central shaft. The motion of the pulley is not transmitted to the central shaft, but to these studs.

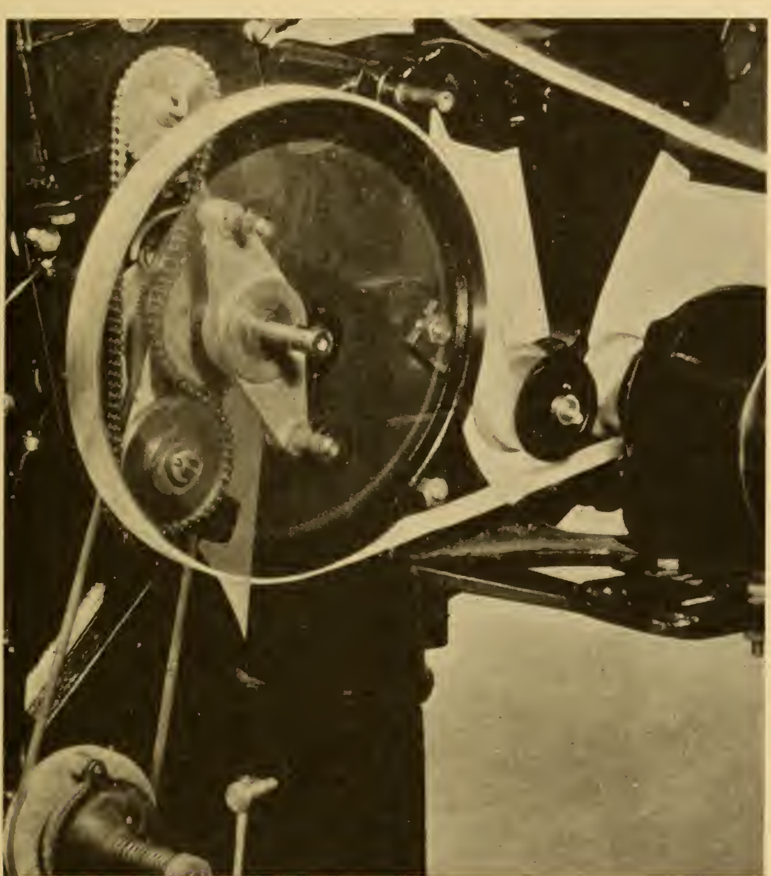


FIG. 151.—Double exposure photograph showing mechanical details of a projector and sound drive.

The construction is revealed in detail by the double-exposure photograph of Figure 151. The studs protrude from two corners of a diamond-shaped casting. They do not touch the pulley directly, but are separated from it by bushings of india rubber. When the pulley revolves the motion is imparted to the studs through the india rubber, which cushions small variations in the motor's action.

The diamond-shaped casting imparts its own smooth motion to the toothed wheel behind it, which in turn moves the sprocket chain that actuates the mechanism of the projector head (above) and the "sound attachment" (below). Belt drive is used for the take-up at the lower magazine.

Damping devices, simple or elaborate, are used with all projector drive transmission systems. Some are more intricate than that of Figure 151, and include complicated-seeming spring filters. All of them, however, can be understood by direct personal examination.

The non-synchronous disc turntable drive is not equipped with a damping device. The platter may fit directly on the shaft of a motor designed to revolve horizontally, or may receive power through a simple worm gear.

Troubles and Care of Motors

(18) The care of motors is discussed in greater detail elsewhere. Here we are concerned only with special items of attention needed by projector drive motors, which amount to little more than exceptional precaution in matters of lubrication and commutator condition, in order to insure that the motor not only runs well, but that its motion is steady and without vibration.

One other matter of exceptional importance in the case of projector drive motors is that of starting torque. Starting must be rapid enough for a smooth changeover but not so abrupt that it may damage either the film or the transmission system. In the case of some projector drive motors the starting torque can be varied by shifting the position of the brushes on the commutator. This is true, for example, of the motor shown in Figure 148. In all such matters reliance must be placed on manufacturer's instructions; details vary much too widely for treatment here.

The same is true of lubrication, both of motors and of transmission systems. The amount of lubricant, type of lubricant and frequency of attention needed by every oil-hole and grease cup in every motor and transmission system now in use cannot be specified in a book like this. In every case manufacturer's instructions are easily ascertained, and should be followed conscientiously.

Where the projector drive motor is a single-phase machine with a separate starter winding the brushes and commutator of that winding, as well as the flyweights that open its circuit when the motor comes up to speed, need very close attention as to cleanliness and proper lubrication.

Troubles and Care of Speed Controls

(19) The centrifugal speed control of Figure 145, 146 and 147 is mechanically similar to the arrangements for supplying current temporarily to the starter winding of a single-phase motor, but under greater strain since it remains in continuous action as long as the motor runs. Cleanliness, especially to provide free motion for the flyweights and to prevent sparking at the brush that supplies power to the centrifugal contact, are vitally important.

The motor control cabinet of Figure 148 needs no attention and gives very little trouble. Any electrical difficulty that may develop is readily found with a voltmeter, since the cabinet contains very few pieces of apparatus and the circuits are simple.

When operating trouble is experienced in installations that use motor control cabinets, the cabinets should be interchanged at the first opportunity. This will indicate definitely whether the difficulty is in the cabinet or the motor, and so simplify the work of running it down.

Vacuum tube control boxes are not very troublesome, but faults that may develop in them are comparatively hard to find because of the number of circuits involved, and their interaction upon each other. In most cases, when difficulty is experienced with these cabinets the "Regulate-Variable" switch they all contain can be thrown to "Variable" and the show run with reasonable satisfaction by manual speed control. In Figure 149 this switch (D-2) open-circuits the path through the 720-cycle tuned filter, L-1, and also open-circuits the secondary of T-2. This change does not affect any of the other circuits, it merely destroys the automatic control of the grid bias of V-4. That bias is then controlled manually by moving the arrowhead at the right-hand side of R-8 and R-9 (which arrowhead, as the drawing shows, is out-of-circuit and meaningless when D-2 is set at "Regulate.") A potentiometer knob mounted on the top of the cabinet makes shifting this arrowhead a simple matter in practice.

If the motor speed responds normally to operation of the variable speed control potentiometer, that is evidence that the difficulty experienced in automatic operation is probably in the filter circuit. If variable operation is unsatisfactory the next step may be to change the tubes, beginning with V-4 as the most sensitive. The milliammeter reading is a helpful indication of the behavior of V-1 and V-2, and the presence or absence of grounds or short-circuits in their output. Beyond this point trouble is traced by voltmeter tests of the various parts and circuits. The manufacturer of these cabinets has drawn up guide charts that would fill many pages of this book, for use of their service engineers, which charts explain what troubles may be indicated by various voltmeter tests. The projectionist will probably find it quite as simple to compare the results of voltmeter tests through a faulty cabinet with those found when the identical test is repeated on the good one. The fact that there are always two of these cabinets, and two drive motors, and that a faulty instrument can be compared in detail with one in good working order, is the best help any man could have or ask in tracing trouble through these devices.

Care of Drive Transmission

(20) The transmission system needs proper, specified lubrication, attention to the tension of its belts or chains —and watching. Watch for evidences of wear or strain that may cause a breakdown, such as worn-down sprocket

teeth or a frayed belt. Watch particularly for evidences of vibration or other irregular action. Flutter and even wows are often difficult for the projectionist to hear in the monitor, above the noise of his projector.

Wherever rubber is used, for coupling or damping (as in Figure 151, for example) watch the condition of that rubber. And be careful of the rubber in lubricating the equipment. Rubber is injured by oil.

Details of the care required by any individual transmission system (lubrication, etc.) are always furnished by its manufacturer,* and should be followed exactly.

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* One tiny, overlooked flaw in the transmission can bring motor, transmission, sound gears and projector head to a sudden, jarring stop, and do a thousand dollars worth of damage. Therefore, give scrupulous obedience to manufacturer's instructions with respect to lubrication and care of your own transmission system, and—watch it.

THE OPERATION OF SOUND EQUIPMENT

Procedure on Taking Charge of a Projection Room, page 626

1. How can a new projectionist obtain information about the details of strange equipment?
2. What detailed information is necessary before equipment can be operated with safety?
3. Why is it necessary to understand the details of the projection room wiring?
4. Why must projection room wiring be charted and tagged?
5. What are inspection forms, and what is their value?
6. What should the projectionist do with regard to inspection forms?

Operation Routine Before Starting the Show, page 633

7. What routine is necessary before starting a show, and why?
8. What inspection is usual before starting a show?

Operation Routine During the Show, page 634

9. What routine is needed during the show, and why?
10. How far is the projectionist responsible for maintaining proper sound volume?
11. How far is the projectionist responsible for maintaining proper sound quality?
12. What is one of the most important things in sound projection.
13. How does poor sound detract from box office receipts?
14. Whose is the fault where poor sound prevails?
15. What is, in most theatres, the only reliable method of monitoring sound volume?
16. Can the box office results of monitoring be directly checked?
17. What must be qualifications of a sound "observer"?

18. What are his duties?
19. Name seven variable factors that require adjustment of volume during the show.
20. How should correct volume settings be determined?
21. Should a stipulated volume control setting be used for all conditions?

Operation Routine After the Show, page 640

22. What are the projectionists' duties after the day's show is ended?

in equipment.

CHAPTER XXXI

OPERATION OF SOUND EQUIPMENT

(1) No matter how familiar a man may be with the principles underlying the action of sound equipment he still needs a great deal of detailed information about any projection room he enters for the first time. The type of information needed may be classed under two heads, namely, detailed instructions for operating the particular make and model of apparatus installed, and detailed knowledge of the wiring, fuse locations, etc., in that individual projection room.

Obtaining Detailed Information

Five possible sources of such information are open to the newcomer. (a) The necessary knowledge may be obtained from the projectionist previously in charge, if he is available. (b) If the theatre is one of the large number that are regularly visited by a sound service engineer, that engineer may be called in to instruct. He will be thoroughly familiar with the system and able to answer all necessary questions. (c) If the projection room equipment has been properly marked and tagged and charted, as explained in detail further on, no instruction will be necessary. Any competent projectionist will be able to run his show by referring to that information. (d) Any brother projectionist who has had experience with equipment of the same make and similar model will prove helpful. (e) Lastly, even if the apparatus has not been properly marked, search of the projection room should turn up the operating instructions that every manufacturer of sound equipment furnishes to his customers.

In the very rare cases where all these aids are missing a competent projectionist will still be able to study out the equipment for himself. He knows what it is intended to do, and the principles on which it works. In addition to having that knowledge he needs chiefly reasonable

FIG. 152.—View showing arrangement of RCA Victor Photophone High Fidelity Sound System speakers behind screen. The three upper units (triplets) are directional baffles. A cone-type dynamic speaker is concealed in each of the three upper boxes. A fourth speaker is concealed in the large, lower unit, which is a special baffle designed to reproduce the very low frequencies only. Compare this with Fig. 144.

time, and willingness to be patient and careful. Switches should not be thrown in blindly, "to see what will happen." A switch on strange equipment should not be thrown in until prolonged examination of its position and connecting wires has given the projectionist a very good idea of what that switch is for and what it does. The first few switches are the hardest to figure out, and the most dangerous to try. Once a few of the controls have been mastered, understanding the rest will prove comparatively simple. Similarly, the projector motor should not be started until one is certain the film has been threaded correctly. When you think you have got it right take a little more time to look at it carefully and figure out every detail of what will happen when those sprockets start to revolve. And so on. All of which is only common sense.

Fortunately, even though a competent and careful projectionist can master strange equipment without help, the situation seldom arises. A man without experience of the type of apparatus installed is not likely to be assigned or permitted to take charge of a one-man projection room unless a sound engineer or the projectionist previously in charge is available as instructor.

Operating Information

(2) To operate a sound system the projectionist needs the following information:

(a) Switches. He must know the location of all necessary switches, and the order in which they are to be turned on in the morning and off at night. He must know the peculiarities of those switches. For example, many amplifiers, like that of Figure 140, use three-position control switches by means of which the filaments of tubes are heated before plate power is turned on.

(b) Threading the film. He must know how to thread the film through the projector and the sound drive, what loops to leave and how large to make them.

(c) Meter indications. He must know what every meter in the projection room should read, what condition any abnormal reading is likely to indicate, and what must be done to remedy that condition.

(d) Lubricating points. He must know what points of the equipment need lubricating, how often, and what type of lubricant to use in each.

(e) Controls. He must know where to find all current rheostats provided in the equipment, how to adjust them, and what the proper adjustment of each should be. He must know how to control volume and how to change over between projectors.

(f) Special information. Under this heading we group an almost endless number of small details, all important. How to re-focus the exciter lamps, for example. Exciting lamp focus is managed differently in different makes of apparatus. Again, how often the storage batteries need to be re-charged (if there are storage batteries) and at what current rate. Or what is the relationship between monitor volume and theatre volume, and what volume from the monitor indicates correct volume in the theatre for average conditions. There is also what may be called, for want of a better term, precautionary information. For example, to what extent does temperature rise in any part represent normal operating condition, and at what point does its increase in temperature indicate trouble?

The projectionist confronted by a strange projection room and strange equipment can, if he has to and if he knows his fundamentals, work out most of the above information for himself, taking time and being very careful not to do any damage in the process of finding things out. But it is infinitely better to secure proper advice from someone who knows, if there is any possible way to do it.

Wiring Information

(3) The work of securing information about the projection room is not nearly ended when all the foregoing have been mastered. The above details are only matters that must be known before it is possible to get the show running. Keeping it running requires further information. Details of the projection room wiring must be known thoroughly or some minor trouble like a burnt-out fuse may hold up the performance for a long time. The

projectionist cannot expect to delay locating the fuse cabinet of a strange projection room until after a fuse burns out. He should know every fuse in the place, and what circuit it controls, before he threads up his first reel of film for an audience.

In addition it is necessary to understand all transmission lines, where they originate, through what connection boxes they run, and where they terminate. This information is absolutely necessary to finding trouble. Naturally, the time to gather it is before trouble has occurred, and not while an audience is waiting impatiently for repairs to be completed.

The details of projection room wiring should always be thoroughly charted. Therefore this is one type of information that will give a new projectionist no trouble if previous incumbents have done their duty. The newcomer will find a detailed chart inside every fuse cabinet, usually pasted up inside the door, showing what circuit each fuse controls and what size it should be. Spare fuses are often placed inside each fuse cabinet; if not, the fuse chart should explain where they can be found. Connection boxes are similarly charted, or if not, each wire or pair of wires is tagged. Connection terminals to amplifiers and other sound equipment are usually labelled by the manufacturer, or they are numbered, and an explanatory diagram is pasted up inside the door or cover. Where neither is the case the wires should be tagged with full information.

In some projection rooms the necessary information relating to the projection room wiring is posted in the form of the sound manufacturer's installation diagram. This should never be trusted without further investigation. Such diagrams only tell what the manufacturer wanted. The conditions existing at the time of installation may have made some departure from that standard necessary. In fact, the actual wiring may be very different from the standard. Sometimes, however, such drawings are modified with pen and ink to show departures from standards, and where this has been done they are probably trustworthy.

(4) If the incoming projectionist does not find all wires carefully tagged or charted he should ask for enough overtime to do the job, calling on the sound service engineer, if the theatre is receiving sound service, to work with him. He should do this for three reasons. First, for his own guidance to quick repairs, in time of trouble. Second, as fair play to his successor in that projection room. Third, because he may be sick or take a day off, and the relief projectionist that replaces him will need the same information.

Other information, in addition to wiring detail, should be made available. Correct meter readings, if not shown by a red line on the dial of the instrument, should be marked on the glass with a red china-marking crayon or in some other conspicuous way. "On" and "off" positions of all covered switches should be similarly marked. So should normal operating positions of rheostats and other controls. Correct battery charging current should be indicated on the charger panel, and so on.

Last, all switches and other controls should be numbered or otherwise plainly identified, and complete operating instructions describing their use in detail then drawn up and posted in a prominent place. These instructions should include everything the projectionist himself would want to know if he entered that projection room for the first time as a new man unfamiliar with its equipment. The manufacturer's information pamphlet should form the back-bone of this data, but must never be regarded as complete in itself for the reason that it does not and cannot take account of individual peculiarities.

Having taken these precautions the projectionist in charge can report sick or on vacation with a clear conscience, knowing that any competent relief man will be able to keep the show running without trouble, and will not injure the apparatus.

Inspection Forms

(5) Since all sound equipment needs both inspection and attention, written or printed routine forms are the

best safeguard against accidental neglect. The routine inspection and lubrication necessary before each day's run should be covered on one such form, while others cover the necessary items of weekly, monthly and semi-annual attention. These latter forms are explained in the next section, which deals with Repair and Maintenance.

(6) If such forms are not provided by the theatre management the projectionist should draw them up for himself. They will save him worry. Merely by following a written or typewritten guide, every morning and every week, he will know that he has taken care of every last detail necessary to keep his equipment in good condition. The fact that he can put a form of this kind before his manager, if any question should arise, will prove of the greatest help to sustaining his side of the argument, and moreover gain him the respect that is always given to a conscientious man who knows his job and is willing to take the trouble to do it properly.

Wherever such forms are provided by the management (which is often the case in chain theatres) the projectionist should add to them any special items of inspection that he finds necessary or desirable in connection with his own equipment. These additional items will in some cases be temporary; for example, a gear that is usually inspected once a month may show signs of wear and need inspection once a week until it becomes bad enough to be replaced. Or they may be permanent, referring to some special weaknesses peculiar to the apparatus or conditions of his own projection room. The fact that some necessary item of attention or inspection is not included on a general form intended to apply to a large number of theatres is no reason for neglecting it.

Now, assuming that the projectionist possesses or has acquired all the detailed knowledge necessary for the proper operation of the one, individual projection room for which he has accepted responsibility, and assuming further that he possesses or has provided himself with all convenient guide forms to routine inspection and operation, let us trace his daily procedure in preparing for the show, starting the show, operating it, and closing down at the end of the day.

Routine Before Starting

(7) It is common practice for the projectionist to start work from fifteen minutes to an hour before the scheduled beginning of the show. Many theatres pay for such additional time, and all will find it worthwhile to do so. Many small items of care, resulting in the aggregate not only in a better performance but in prolonging the life of equipment, cannot be attended to properly while a show is running.

(8) The procedure before the show varies from theatre to theatre, and according to the type of apparatus. In general it runs approximately as follows:

(a) Apply lubrication, according to a prepared routine that makes certain nothing is overlooked.

(b) Check condition of storage batteries (if used) and of dry cells (if used).

(c) Switch on the system, and check all meter readings.

(d) Inspect exciting light focus of both projectors, adjusting it if necessary.

(e) Make click test for sound. This test is made by removing the sound gate (if necessary) and interrupting the exciting light. Moving a pencil or a finger rapidly through the beam is the usual method. A rumbling or clicking sound will be heard in the speakers if the system is functioning. Click test of the disc reproducer is made by brushing a finger against the needle. The microphone is tested by speaking into it. These tests should be applied to both (or all three) projectors, to all disc reproducers, synchronous or non-synchronous, and to all microphones that will be used in the course of the day's show.

(f) Where there is more than one stage speaker the click test should be repeated for each speaker separately, to make sure that all are working. This last, however, is not possible in all theatres. In some the speakers cannot be switched on and off individually.

(g) In some theatres the above tests are followed by a trial run of sound, as a check upon quality.

The above list represents what is perhaps average procedure. In any individual projection room there will be other items, perhaps many others, that can and should be checked before the show is started. In this matter individual conditions are the only guide.

Routine During the Show

(9) Having completed his preliminary inspection the projectionist threads up the first two reels of the show and waits for the starting buzzer or for the scheduled starting time.

Where two projectionists are engaged they commonly check on each other's work in threading up the film. This is a routine precaution of inestimable value.

At schedule time or at a buzz from below the projectionist starts the motor of the projector that carries the first reel of the performance, switches his fader to that projector as soon as proper running speed is reached, and adjusts his volume control, if necessary, for that monitor volume which corresponds to correct volume in the auditorium.

His responsibility during the show with respect to threading, removing, inspecting, repairing and storing film is explained on Pages 167 to 200. His responsibility with respect to projecting a bright, clear and steady picture requires no explanation.

(10) His sound responsibility sometimes includes listening to the monitor and adjusting volume whenever necessary to compensate for inequalities in the recording, but this is poor operating practice. As explained below, volume should always be controlled by signals from the auditorium. When the monitor is used it should always be kept as low as possible, since if heard in the auditorium it sounds like echo coming from the rear wall. Even where the projectionist is solely responsible for volume the monitor is often turned off entirely, except for changeovers, during pictures in which the recording is known to be of constant level.

The projectionist observes his meters periodically, and especially often at hours when the power line voltage is subject to change, adjusting his rheostats or line voltage controls as circumstances indicate.

He follows a pre-established routine of checking his equipment during the day for evidences of excessive heating or other signs of possible trouble, paying special attention to any part that may have given indications of weakening.

(11) The projectionist is sometimes held responsible for noticing bad quality or noisy sound, but such matters should always be checked in the auditorium. Projectors in action are unavoidably noisy, and many sound troubles cannot be heard in the projection room. An observer in the auditorium must note them, and telephone the projectionist of their existence. With some troubles, misalignment of the lateral film guides, for example, the observer in the auditorium must co-operate with the projectionist via telephone if the difficulty is to be cured completely while the reel is running.

Likewise, as has been said, the projectionist in some theatres is held responsible for controlling sound volume by means of his monitor. This also is very poor practice.

Good sound is an extremely delicate matter, requiring constant attention.

(12) The one most important thing to be attained in the reproduction and projection of sound in a theatre is *naturalness.* The object is to have the theatre patron forget he is seeing a motion picture and hearing "canned" sound, and become so lost in the play that he visualizes the screen shadows as real, and the sounds as sounds from the real man, woman, instrument or whatever the seeming source may be.

This is a condition that cannot be attained if the sound be too loud, too low, or unnatural in any other way. If the sound (words for example) be hard to understand, the mind automatically seeks the reason and remembers that it is not hearing sound from an original source. Thereupon it automatically blames the theatre equipment or the projectionist or both for the destruction of its happy illusion, and there is dissatisfaction.

(13) In a considerable majority of our theatres ears are often obliged either to hear unnecessarily loud sound, or else are under constant strain to distinguish more than an occasional word or sentence of the dialogue. Where either condition obtains, discriminating theatre patrons (and their number is rapidly increasing) either lose their taste for motion pictures or else seek some place of entertainment where sound projection is better managed. If there be none such available, the interval between their

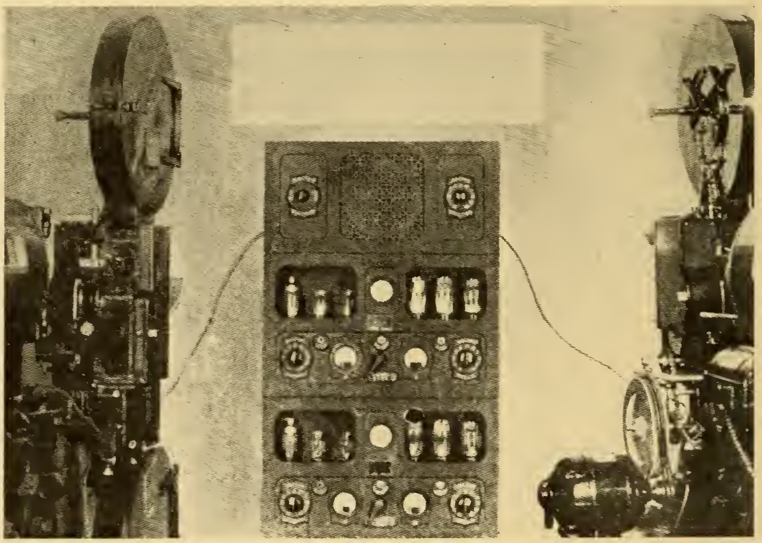

FIG. 153.—Double-channel amplifier with built-in monitor speaker in top panel. Compare with position of amplifier in FIG. 141.

theatre visits lengthens very noticeably and the theatre box office suffers.

(14) Such conditions are not ordinarily due to any fault of the projectionist. The fault rests squarely on the shoulders of the management or the manager. It is due entirely to the fact that either he has not installed any system of volume control, or if he has one it fails in its purpose.

The monitor horn unfortunately cannot be made to supply a reliable guide to auditorium sound volume. It serves merely to assure that the sound equipment is operating and for the receipt of sound cues.

(15) In all except a very few theatres the only practical system of volume control under all conditions is by means of an "observer," and a bell and buzzer located preferably on the front projection room wall, between the motion picture projectors.

This bell or buzzer is controlled by a bell button located in some inconspicuous place in the rear of the auditorium, not too near an entrance. On the back of one of the aisle seats in the rear row is usually the best location.

This bell is for use by the observer, who by a prearranged signal code is enabled to advise the projectionist as to sound level.

Provided the right person is selected for the observer, and further provided he attend solely and continuously to that duty, the results will be very greatly improved and the cost of the observer unquestionably will be much more than covered by retention of patronage and new patronage attracted by excellence of the entertainment.

(16) This is, however, something that unfortunately cannot be directly checked. It is a matter upon which the manager must use common sense and his reasoning powers. His showmanship must be his guide.

(17) No person other than one having normal hearing power can serve acceptably as observer. His hearing must be in no degree defective; also it must not be abnormally keen. He should have some sense of dramatic action and be musically inclined. These last named qualities are of very great value in the efficient control of sound volume. (18) He must not stay in one place, but pass occasionally from one part of the auditorium to another, including the balcony, and keep close watch on sound conditions in all parts of the theatre. He must be a man who has some appreciation of the importance of his position and of the value of excellence in monitoring.

(19) Many factors tend to make volume changes imperatively necessary if optimum results are to be attained.

First, there is a vast difference in volume demands as between an empty auditorium and one that is well filled.

Second, audience movement, noise in the aisles caused by patrons walking in or out.

Third, auditorium reaction to comedy or effects that produce loud laughter.

Fourth, cold weather. Audience wearing heavy clothing.

Fifth, hot weather, with consequent light clothing.

Sixth, departure of a portion of the audience, or the theatre gradually filling up.

Seventh, low recording, or some fault of the equipment that lowers volume.

These various conditions are for the most part highly variable. Only low recording, equipment fault and audience clothing are likely to create a condition lasting without appreciable variation throughout a whole show.

There are, too, atmospheric conditions that change things. A clear, frosty night, for example, will usually call for a lower volume setting than will a damp, warm night.

(20) During the first projection (preview if one is had) of a picture, the average volume control number should be noted for each scene thereof, and the same noted on the cue sheet (with the mental note, however, that if it be a preview with an empty theatre the real setting with a full house will probably be one or two numbers higher.) The setting will of course be directed by the observer through his signal bell. This method gives each scene the best possible rendition.

(21) Managers should never attempt to regulate sound by stipulating a certain volume control number for all conditions. Or for the use during each day a production is shown. There are too many conditions constantly demanding change in volume. A volume control position that might be quite proper for a scene today may be all wrong tomorrow for any one of several reasons.

No theatre pretending to provide high class entertainment can afford to operate even for one day without a well trained observer attending strictly to business during every moment of the show. If there be no observer, or one entrusted with other duties, while it is quite true that business may show no observable decrease or harm, a reputation for poor or unreal sound effects will always, if invisibly, be unfavorably reflected in box office receipts. The understanding manager—he who has that undefinable quality called "Showmanship"—knows this to be true and refuses to take chances on loss of business through defects that can be remedied.

Unfortunately it is a much too frequent occurrence for theatre patrons to be obliged to sit through a show where an unwise manager has made no adequate arrangements for sound monitoring. The projectionist, having nothing to guide him except a monitor speaker, which is as unsuitable for the job as such a manager is for his job, cannot possibly help the sound running wild, blasting the ears at times and again straining them to distinguish dialogue.

Although it is difficult to make some theatre managers realize the value of high class projection, the thing is always perfectly obvious to him who will take a minute to get his whole mind off the matter of saving a few cents and concentrate upon making a few dollars added box office returns.

Unquestionably, lack of adequate sound monitoring in years past has cost theatres as a whole hundreds of thousands of dollars in business loss.

Too much volume is a more common, and always a much more serious fault, than too little. Audiences will soon complain if sound is too low. But not being sound experts they don't know that the intense discomfort they experience at other times is created partly by a too savage assault upon their eardrums and partly by excessive reverberation (caused by excessive volume) which makes sound difficult to understand. All they know is that they automatically, and very often subconsciously, associate the idea of that theatre with the idea of acute discomfort.

In some cases of poor volume control the trouble has been traced to the use of the wrong man for observer. Many persons have defective hearing and don't know it.

At some convenient time after hours the entire theatre staff should listen to sound and compare what they hear (especially with respect to high frequencies) when the volume is progressively lowered. This test will reveal some member of the staff as having good, average hearing (not too good). This person should either be chosen as observer, or, if his other duties prevent this, as a "standard listener" against whom all candidates for the post of observer should be tested by a similar procedure. A multiple-frequency test reel, such as the one offered by the Society of Motion Picture Engineers, provides ideal sound for this test.

Routine After the Show

(22) Any defects in the condition or functioning of the equipment that may have been discovered during the day, either by inspection or in the course of operation, and were not completely and finally cured at the time, should be repaired before the projectionist leaves the theatre. Only very minor matters should ever be left to the pre-show routine of the following morning, and in every such case the projectionist should take care to post up a reminder for himself.

Reminders should always be posted in connection with any matter whatever that is carried over another day. If, for example, a certain part has shown indications of possibly causing trouble, and needs watching, always thumbtack a reminder to that effect on the bulletin board or on a convenient wall space.

Such reminders should of course be very complete and explicit if a relief projectionist or crew is to be on duty the day following.

Storage batteries (where used) are often put on charge after the end of the day's show, care being taken to use a low rate that will not overcharge the battery when no one is present to watch it.

In many theatres it is the practice to end the day's work by submitting a written report to the manager. It also is a common custom at the end of the day to draw up and submit to the manager a list of supplies needed. Thus if a tube burns out, for example, a new one is ordered without delay, and the theatre's stock of emergency spares never becomes depleted.

MAINTENANCE OF SOUND EQUIPMENT

Finding Trouble, page 645

1. What is always the first step in finding trouble of any kind?
2. What is the second?
3. If the trouble occurs during the show, what is most necessary in finding it?
4. What are the qualifications of a good trouble-shooter?
5. Why does a *good* workman never blame his tools?
6. What tools are necessary to do a proper job of trouble-shooting in sound apparatus?

Repair of Trouble, page 650

7. What is a temporary repair?
8. Why are temporary repairs necessary and valuable? When should they be avoided?
9. Is a permanent repair completed when the trouble has been entirely removed? Why not?
10. What are the requirements of a permanent repair?

Types of Trouble, page 652

11. Explain how the cause of complete loss of sound can be traced down and remedied.
12. Explain how the cause of low volume can be traced down and remedied.
13. Explain how the cause of poor quality can be traced down and remedied.
14. Explain how the cause of failure of a power supply circuit can be traced down and remedied.
15. Explain how the cause of a foreign noise can be traced down and remedied.
16. Where is the use of headphones helpful?

17. What procedure can be followed in dealing with intermittent troubles?

Maintenance, page 656

18. Name the two chief requirements of good maintenance.
19. What paper help is necessary to insure reliable operation?

Inspections, page 656

20. What routine inspections are necessary to any sound system?
21. How can the projectionist easily provide himself with thoroughly useful inspection forms?
22. What items of attention should be included on the daily inspection forms?
23. What items of attention should be included on the weekly inspection form?
24. What items of attention should be included on the monthly inspection form?
25. What items of attention should be included on the semi-annual inspection form?
26. Does the responsibility of the projectionist end when he has completed his inspections and properly marked the forms?
27. What procedure must always accompany or follow inspection?

Soldering, page 659

28. Why is good soldering for a power circuit poor soldering in a sound circuit?
29. What are the requirements of good soldering in sound work?

Testing Sound Parts, page 660

30. How can resistors be tested in the projection room?
31. How can inductances be tested in the projection room?
32. How can transformers be tested in the projection room?
33. How can condensers be tested in the projection room?
34. How can tubes be tested in the projection room?

PURCHASING, PAGE 661

35. What is good maintenance practice with respect to stocking spare parts?
36. What is good maintenance practice with respect to selecting parts and supplies?
37. What paper help is indispensable to economical maintenance?
38. What maintenance factors should be considered in the selection of a new sound system?

CHAPTER XXXII

MAINTENANCE OF SOUND EQUIPMENT

When trouble of any kind occurs (if, for example, sound stops) the usual condition confronting the projectionist is that his difficulty may be almost anywhere in the entire theatre. It may be backstage among the speakers, or down cellar at the meter fuses, or up in the hanging ceiling in the speaker supply lines, or it may be, and most likely is, somewhere in the varied apparatus and wiring of the projection room.

Finding Trouble

(1) Therefore the first step in finding any kind of trouble is to find out, not what, but where it is. Until that much has been done the projectionist cannot even begin to look for its cause because he will have little or no idea of where to start.

How any particular kind of trouble may be traced down to some one piece of apparatus or some one circuit is explained further on under appropriate headings.

(2) When the difficulty has been so far isolated that the projectionist is able to say with certainty that it lies in this amplifier or that control cabinet or whatever the apparatus may be, the exact fault is hunted inside that apparatus. How to find troubles inside each component part of a sound installation has already been explained in detail.

(3) When trouble occurs during the course of a show speed in finding it and repairing it is of the greatest importance. Every minute of delay in restoring the performance may mean another dollar or another ten dollars in box office refunds (depending upon the class of theatre) and just that much more patron dissatisfaction. Therefore the projectionist confronted with unexpected

trouble must know exactly what to do and precisely how to go about doing it, without having to stop for prolonged reflection. The competent projectionist will be mentally prepared for any type of difficulty he can possibly anticipate, and when it occurs go about restoring his show without waste of time.

(4) Since time is of such vital importance in repairing trouble, the first qualification of a good trouble-shooter is that he keep cool in emergency. If he knows his equip-

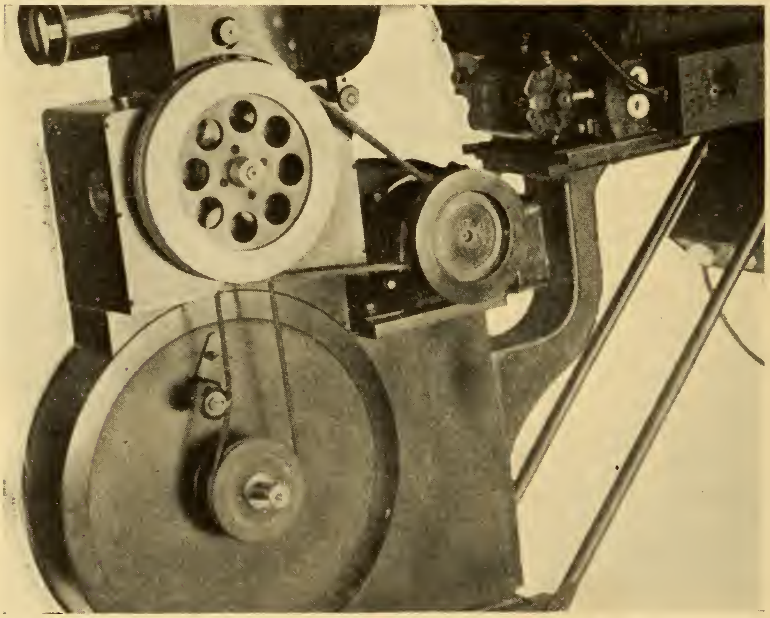

Fig. 154.—Belt-driven sound-head.

ment thoroughly, in principle and in detail, he will find it easy to keep cool and to work fast and systematically. If he is doubtful and uncertain of his knowledge of his business he will probably become flustered, and then nothing but undeserved good luck can help him.

The qualifications of a good trouble-shooter are therefore coolness, full and detailed knowledge of his business, and the self-confidence that only such knowledge can give.

One other qualification is the possession of proper tools for his work. (5) A good workman never blames his tools because he knows the value of obtaining good ones. He knows that having the proper tools and keeping them in good shape is the only condition on which he can do good work. The projectionist is entitled to demand of the theatre the test equipment necessary to find trouble quickly and accurately. If such equipment is not supplied a broken wire may take two hours to find or sound quality continue consistently bad.

Instruments Used in Trouble-Shooting

(6) Perhaps the most necessary single instrument for trouble-shooting is a pair of good, high-resistance headphones. Next to these, and practically as indispensable, is a multiple-range combination voltmeter-milliammeter of good quality and high internal resistance.

Do not buy either cheap, low-resistance phones or cheap, low-resistance meters. They are not only useless for sound work, but may prove seriously dangerous to the apparatus because they pass too much current. Buy such equipment from a reliable source only and explain the purpose for which it is to be used.

A rectifier-type a. c. voltmeter and ammeter is likewise extremely useful. The same instrument can be used as an output or volume indicator. The supplier will provide a correction chart by means of which voltage readings of this meter can be converted into decibels, the units in which sound volume is commonly measured. Sound power can be expressed in either decibels or watts. (The decibel is usually chosen because it is the more convenient unit. In the same way water can be measured in quarts or in ounces, but it is generally more convenient to figure in quarts.)

The theatre should by all means have a reel, or at least loops, of test film. The reel is preferable, and lasts longer. Either reel or loops should contain sound recording of excellent quality for testing the system, and in addition pure-tone recordings of a number of frequencies. If disc is of importance in the theatre records of high quality recording and frequency test records should also be available.

The high-quality sound recording serves to check the equipment not only for generally good response but also for such particular troubles as flutter. Piano recordings show up flutter very plainly, and are often used for this purpose. The frequency recordings are used with an output meter or volume indicator. For this purpose it is best to use a reel containing a number of frequencies, all recorded at the same level. The volume control is not changed while this reel is run. The output volume is measured by the meter, and should be the same for all frequencies that the system is intended to reproduce. In some systems, however, the response at certain frequencies is intentionally made low or higher; this may be done to compensate for acoustic conditions of the theatre or for other reasons. We have seen that the amplifier of Figure 139 included arrangements for varying the frequency response. In such cases the test reel and the output meter are used to determine when the desired modification has been obtained, and periodically thereafter to see that the response of the system has not changed.

The output meter or volume indicator used with the test reel for this purpose is really a disc-type-rectifier a. c. voltmeter, calibrated to read directly in decibels. As already stated, any voltmeter of the same type built to operate within the same range of power can be used instead by means of a simple chart, furnished with the instrument, to convert volts into decibels.

Another instrument that is always useful, and with some types of equipment indispensable, is a combination circuit-tester tube-tester of the kind used by radio repair men. These instruments are made in quantity production for radio dealers, and hence are not excessively costly. The later models are capable of checking the large tubes and high-voltage circuits used in sound equipment. A tester of this kind often contains only a single meter but a large number of switches. By operating the switches in accordance with instructions the same meter will read a wide range of d. c. volts, a wide range of d. c.

amperes, a wide range of d. c. milliamperes, several ranges of a. c. volts, a. c. amperes and a. c. milliamperes, and can moreover be used, with a conversion chart, to read decibels.

Simpler equipment that is also useful includes a test buzzer operated by a flashlight-type dry cell. This is very useful for testing through conduit wiring. It should not be used, however, without the precaution of disconnecting all apparatus that contains a sound transformer or a sound choke coil. Buzzer current must never be sent through those parts.

The small patented device called "Test-a-lite" is very handy in checking power circuits. It tells whether any circuit carrying more than 100 volts is "alive," and if so whether it is carrying a. c. or d. c.

In addition to instruments, the trouble-shooter needs detailed information, as set forth on Page 492. Checking circuits with a meter is thankless work unless the details of the wiring are known thoroughly or plainly visible on a drawing. Wiring diagrams accompany practically all sound equipment, either in the manufacturer's instruction book or pasted up inside each amplifier or other piece of apparatus. If they are found missing, ask or write for duplicates at once. Diagrams of the external transmission wiring between different parts of the system should also be available. These should, in every case, be compared with the actual existing wiring, using the test buzzer if necessary, to make sure that the drawing is an accurate representation of the circuits of that projection room, and if not, the drawing should be modified accordingly. If the theatre is receiving regular sound service the service engineer will be able to provide the proper drawing and modify it correctly if necessary.

With any of the more intricate sound systems, failure to have this information on tap may mean that a very simple trouble will tie up the show for hours, while the work of making complete and permanent repairs has been known, under such circumstances, to take several days, most of the time being used in tracing out unknown wires.

Temporary Repairs

(7) A temporary repair is any expedient whatever that will restore the show in the shortest possible time. It need not be a remedy or rebuilding of any kind. It may be no more than switching out a faulty amplifier and running with the other amplifiers of the system. It may amount to a lamp cord run as a temporary transmission line outside of conduit until time can be found to trace down the break or short in the regular wires. Although cutting out an amplifier may result in low volume, and temporary transmission lines outside of conduit may cause noisy sound, either of these troubles may be preferable to tying up the show altogether until permanent repairs can be made.

Temporary repairs also include substitution of substandard or "haywire" parts while awaiting delivery of a proper replacement. The local radio store will be able to provide anything from a condenser to a complete amplifier. Storage batteries rented in emergency from the nearest garage will substitute temporarily not only for the theatre's storage batteries but also for its sound supply rectifiers or motor generator.

The possibilities of ingenious temporary repairs are almost limitless, but we shall say little about them here because such improvisations are always dangerous. (8) Temporary repairs are necessary and invaluable when they serve to restore the show faster than any other procedure could. They should always be avoided, however, (a) when permanent repair can be made with little more delay, and (b) when the projectionist is not entirely certain that damage to other apparatus is impossible.

Because they are dangerous except when applied by men who know exactly what they are doing, including the resistance or impedance of every part and circuit involved, temporary repairs should be planned carefully in advance. It is excellent practice to ask the sound service engineer, if there is one, or to inquire by mail of the manufacturer of the equipment, just what emergency steps may safely be taken in case of this, that or the other trouble.

Permanent Repairs

(9) A permanent repair involves not only restoration of the equipment to proper and permanent operating condition, but in addition every step of precaution that can reasonably be taken to avoid recurrence of the same trouble, or to avoid delay in the show if it does recur. This may quite possibly involve changing some portion of the equipment. In unusual and extreme cases it may mean buying a new sound system. Permanent repair may also involve taking advantage of the occasion to add some intended and valuable improvement, the installation of which has been delayed because of the cost of tearing the old system apart.

(10) In any case, a permanent repair is never completed until, first, the system is giving the best results possible to its design, and, second, until every reasonable precaution has been taken against further interference with the show.

Let us review the foregoing briefly:

The first step in finding trouble is to determine which portion of the system is responsible.

The second is trace down the faulty part or wire or contact within that apparatus or circuit.

Speed in finding trouble is of vital importance because interruptions to the show are very expensive, both directly in box office refunds and indirectly in loss of patron confidence.

The trouble-shooter must keep his head, and therefore he must possess all the knowledge, general and detailed, that is necessary for self-confidence.

He requires proper tools and instruments to do his work.

Temporary repairs are very helpful in restoring the show quickly, but likely to endanger other apparatus unless they have been carefully planned in advance.

Permanent repairs are not complete until everything possible has been done to prevent re-appearance of the same trouble.

Let us now apply these necessary generalities to the problems of finding different classes of trouble.

Loss of Sound

(11) This is usually the easiest trouble to find. Headphones applied to the sound transmission lines should quickly locate the apparatus or circuit at fault. The difficulty is then checked through that apparatus as has previously been explained in connection with the description of each sound system component. Depending on the circumstances, it may or may not be advisable to delay that detailed work until a temporary repair has been made to restore the show.

However, if the equipment is provided with meters and signal lamps even the brief time necessary for a headphone test can sometimes be avoided. A momentary glance at those indicators may locate the difficulty at once by revealing that some power line has failed. In that case headphones need never be used. The power line is run down with a voltmeter.

The remedy to be applied depends, of course, upon the cause, and involves repair of the broken circuit, elimination of the short, or replacement of the faulty tube or other part, as the case may be.

Low Volume

(12) This trouble is harder to trace than complete loss of sound. It may be possible to judge by a headphone test at what point the amplification is insufficient or the line loss excessive, but such investigation may also result in nothing more than doubts and surmises. It is, however, simple enough to determine whether the fault is associated with either projector. If it is, then all voltages to the faulty machine should be checked with a meter, if not, then those supply voltages that are common to both projectors, and after them to the amplifier should be investigated in the ways hereafter explained. In some cases, finding the cause of low volume may require a

long time and much patience. In very rare instances it may prove necessary to borrow duplicate parts in order to determine by comparison just where the trouble lies.

The volume indicator is a valuable instrument in this type of trouble. Knowing what the volume of the amplifier's output should be, with the test film previously used, the projectionist can tell by means of this instrument whether the cause of low volume is in the projection room or in the speaker circuits. If it is in the projection room and not confined to one projector either the amplifier or its transmission lines must be responsible. If there be both a voltage and a power amplifier the output meter (by comparison with previous results) may be able to determine which of the two is the faulty one.

Poor Quality of Sound

(13) This type of trouble will sometimes be found readily, perhaps with the help of headphones. Sometimes it proves more obstinate than any other.

The ways in which each separate portion of the sound equipment can cause poor quality have already been described in detail. In extreme cases it may be necessary to investigate them all, one at a time.

Fortunately, it is very often possible to determine the cause of poor quality by spending a little time in the auditorium and listening carefully. Once the difficulty has been classified, as, for example, flutter, wows, loss of high frequencies, loss of low frequencies, the work of finding its cause is immensely simplified. The various conditions that can cause these different troubles have all been explained. Flutter and wows are due to imperfect functioning of the drive system. Loss of high frequencies may be caused by nothing more than bad focus of the exciting light, or yellow or insufficient exciting light. However, an open-circuited by-pass condenser in an amplifier can also be responsible. Or the power supply to the high frequency speakers may be faulty. Loss of low-frequency response may be due to a similar defect in connection with the low-frequency speakers.

Since bad sound quality is not a single trouble, but may be any of a great number (some acoustical), there is no single remedy and no simple way of running it down. Patience, common sense and knowledge on the part of the trouble-shooter are indispensable for fixing bad sound. The output meter and the test film will prove of great help not only in determining whether the frequency response has deteriorated, and if so to what extent, but also in measuring precisely the result of any remedial measures that may be tried experimentally.

Trouble in Power Supplies

(14) The voltmeter is the necessary instrument for running down a power supply line or power supply equipment. The first step should, in most cases, be to apply the meter to the switch or other output terminals of the power source. This shows at once whether the trouble is in the source or in the output line. Continued voltmeter tests must reveal the difficulty, unless, as explained further on, it be intermittent.

Hums and Noises

(15) This type of trouble, again, does not represent a single condition, but involves any one of a vast number of possibilities.

The first step is to listen carefully to the hum or noise, attempting to classify its cause by what it sounds like.

The experienced projectionist will recognize at once the sound of sprocket-hole noise and dividing-line noise, both caused by mis-adjustment of the lateral guides. He will likewise find little difficulty in distinguishing between the low-pitched line-frequency hum and hums or whistles of higher pitch. Furthermore, he will be familiar with the rasping, rattling sound of a bad or dirty connection. These are the three commonest forms of foreign disturbance.

(16) Headphone tests may be helpful in dealing with them, by determining, for example, that the cause is in the voltage amplifier and not the power amplifier, or vice versa.

Line-frequency hums may be caused by amplifier conditions described in connection with the construction and functioning of amplifiers. They may also be caused by exposure of the photo-cell to the projection room light, if that is created by a. c. Another cause may lie with the ground connections, and this is a more tricky matter, in which trouble-shooting becomes largely experimental. The earlier sound systems often used a number of grounds, and sometimes line-frequency hums could be cured by adding still others, and sometimes by removing some of those already in use. The modern tendency is in the direction of a single ground connection for all the equipment. Corrosion or bad contact at this or any connection may easily create line-frequency hum in the sound.

Hums of other than line frequency are rare. They may; however, (as already explained) be caused by feedback in an amplifier. Or by loose connection in a grid circuit.

The crackling, buzzing or fizzing or rasping sound caused by most imperfect contacts can sometimes be run down by headphones, which may indicate what amplifier, supply line or other part of the system is the source of the trouble. Sometimes, however, much patience is needed before trouble of this kind is traced to its ultimate cause, which may be, perhaps, no more than a defective fuse.

Intermittent Troubles

(17) Any of the above troubles becomes infinitely harder to find if it does not represent a permanent condition, but one that comes and goes. In such cases tests have no meaning unless they are applied at a moment when the trouble is present. The fact that an experimental remedy seems to work likewise means nothing with a trouble that constantly disappears of itself.

One very helpful procedure in these difficult cases is to attempt to make the trouble worse, rather than better. Wires are tugged, ground connections are rattled, rheostats and switches are operated rapidly and jerkily, tubes are tapped and panels tapped or shaken in an effort to cause or to aggravate the trouble and thus determine its location.

If these methods do not work the next best remedy is patient testing and searching at every possible moment when the trouble is present. Ultimately this adds up to continuous investigation of a trouble continuously present. In some cases, however, the process may take much too long for the comfort of audiences and the welfare of the box office. In such instances it is sometimes (not invariably) possible to make faster progress by borrowing duplicate apparatus for temporary substitution, or by running temporary duplicate circuits. Both these last steps, of course, represent remedies of desperation.

The foregoing does not exhaust the subject of trouble-shooting. A book much longer than this one could be written on that subject. Every case of trouble is a new and different experience to which old rules may apply and may not. Such things as complete loss of sound or power are nearly always easy to find, but an intermittent hum or noise may defy the world's best trouble-shooter for days or even weeks. We have outlined here methods of trouble-shooting that are likely to afford quick relief against all the commoner causes of sound trouble. For very rare troubles, or for common troubles arising out of a very rare cause, knowledge, common sense and persistence constitute the only possible rules.

Requirements of Good Maintenance

(18) Good maintenance requires (a) that the equipment be kept in condition for reliable, trouble-free operation at all times, and (b) that it perform its functions at the lowest possible cost.

(19) Written, typewritten or printed forms for daily, weekly, monthly and semi-annual inspection are necessary to insure reliable operation. Without such forms the most experienced projectionist can never feel sure that he has remembered every necessary item of attention or adjustment.

(20) All the inspections just mentioned are not necessary in every theatre. Daily inspection is invariably

necessary. But the weekly inspection can sometimes be eliminated in favor of inspection every second week. Occasionally, if inspection is held every other week, the monthly inspection can be abandoned, certain additional items of care being included in the bi-weekly form. With equipment in good condition, new, but not too new, annual inspection may be used in place of one every six months.

The exact requirements vary according to the reliability of the sound equipment, its age, its condition, the nearness of the theatre to sources of engineering help and emergency supplies, the class of audience and corresponding importance of keeping the show running without interruption or defects, the alertness and experience of the projectionists, and several other factors.

But it is always necessary to inspect parts of the equipment daily, and other parts at reasonably short intervals, such as every week, every other week or every month. Lastly, some things that give little trouble and are difficult to get at must still be looked over once in a long while, every six months or every year.

These precautions not only protect the show, but also save money. Breakdown of one part very often will damage or endanger a dozen others. This is true in the drive system, it is true in amplifiers, and true in connection with power sources. Again, setting aside the undesirability of trouble from the point of view of audience dissatisfaction and possible box office refunds, the mere cost of making repairs may, and often will, be much greater than the cost of following inspection routines that catch and rectify the trouble before it grows large enough to need extensive repairs.

(21) The projectionist can draw up his own inspection forms. If printed forms are provided by the management he should modify them to take care of special conditions in his own projection room. It is not difficult to draw up an inspection list. In explaining amplifiers, speakers and other parts of a complete sound system we have listed the commoner troubles to which each is subject. The projectionist should study every separate part

of his sound installation, carefully considering what possible troubles must be guarded against in each, and how often it should be necessary to inspect for their symptoms. His inspection lists are prepared accordingly. Experience with the installation will naturally call for some modification or expansion of those lists from time to time.

If the theatre is receiving regular sound service only the daily list is necessary. The sound engineer will take care of everything else, insofar as the sound equipment is concerned, and the daily form should be submitted to him for his comment and advice.

(22) The daily form lists every item that needs care or attention daily, but just what these will be depends on individual conditions. (23) The weekly list mentions everything that needs to be done or watched weekly. The weekly inspection, if lengthy, need not be done all at once. It can be divided into parts, and some of it done each day. If there is no weekly inspection, but only one every other week, some items, which cannot safely be neglected that long, will have to be added to the daily form. (24) The monthly list includes attention to those parts that wear out rather slowly, and do not need very constant watching. Upon occasion, some part in poor condition may be transferred, pending replacement, to the weekly or even to the daily list. (25) The annual or semi-annual inspection is usually very thorough, including all those parts of the system that cannot be inspected often because they are difficult to get to, or because (as with the innumerable soldered connections) too much time is needed to do a thorough job of going over them. The annual check-up also includes those that are very slow to wear and consequently need attention only rarely.

Detailed knowledge of local conditions and good common sense are the necessary requirements for preparing such lists.

(26) The purpose of inspections, of course, is to insure that all necessary adjustments, repairs and replacements are made in advance of serious trouble. Inspec-

tion alone, not followed by adjustments, is meaningless. Minor matters, such as cleaning and lubrication, are attended to in the course of inspection. (27) Matters that cannot be cleared up promptly are noted on the form or list, which of course is never finally filed for record until every repair it indicates has been completed.

Soldering

(28) This factor in sound repairs is important enough to rate special attention, particularly since many projectionists fail to realize that what is good soldering in power work may be atrociously bad soldering in sound work. Soldering is used in power lines very largely to prevent the connection from opening, not particularly to secure low-resistance contact. The comparatively large voltage and current of a power line are not troubled by slight corrosion, or minor variations of resistance. But sound current may be as small as a micro-ampere (a millionth of an ampere) and sound voltages are very often of the order of one volt. Consequently slight variations in the resistance of a sound connection may create noisy sound, and a prolonged headache in the trouble-shooter who tries to run down the cause. Appreciable or even slight corrosion may result in complete loss of sound.

(29) Sound soldering is seldom done with an open flame. A copper is used, hot enough for the work. It is bad practice to melt the solder and let it drop on a cold wire. It is good practice, wherever possible, to heat the wire and let it melt the cold solder. Occasionally the contact stud of a condenser or transformer will refuse to heat readily. Prolonged application of the copper is dangerous in such cases. The stud may refuse to heat to the proper temperature until the internal wires or insulation have been seriously damaged. A hotter copper should be used. Open flame should be used only with great caution.

Sound connections are not made with acid but with rosin. Acid may cause corrosion.

A person experienced in sound soldering can safely create a physical connection by splicing two wires, or a wire to a terminal post, and then soldering the splice, but this practice is dangerous in hands that are not thoroughly skilled. The novice at sound soldering should tin both terminals and solder them together, providing no physical bond except the solder itself. After the joint has cooled, tug hard at one of the wires. If the joint was properly made it will not yield. But this valuable test is useless if there is a physical splice aside from the solder. That is why such splices should never be used by the novice.

Testing Sound Parts

There are two reasons why sound parts are tested in the projection room. One is that such tests may be a necessary step in trouble-shooting. The other is equally important; no part should ever be stocked as a spare for use in emergency until tests have shown that it can be relied upon when needed.

Testing Resistors

(30) Resistors are tested by use of an ammeter, a voltmeter, and application of Ohm's law. Such tests, however, check only the continuity and resistance of the part, not its current-carrying capacity. The latter factor cannot readily be checked in the projection room.

Testing Inductances

(31) The inductance of coils is not usually measured in the projection room. They may be checked for short-circuit with a. c. and an a. c. milliammeter. Inductance coils* show high impedance to a. c., which will be diminished or altogether absent if the coil is short-circuited internally. They are checked for open circuit with d. c. and a d. c. milliammeter, since direct current should pass through them with little loss unless the wire is broken inside.

Testing Transformers

(32) For projection room testing purposes the trans-

*Never test a speech choke coil with more current than it is intended to carry in actual use.

former may be regarded as an instrument made up of two or more choke coils, each of which is tested separately. When there are many terminals the transformer casing, or the wiring diagram of the apparatus in which it was used, will show the internal connections.

Warning: Never test a speech transformer with more current than is necessary to operate a high-resistance voltmeter.

Testing Condensers

(33) Some combination circuit-testers-tube-testers contain provisions for measuring the capacitance of condensers, but this is not usually a matter for projection room test. Condensers are tested for internal short circuit with d. c. and d. c. ammeter or milliammeter, or a trouble lamp. Only short circuit of the plates will permit d. c. to pass through a condenser (except for a momentary charging current). Internal open-circuit is tested with a. c., which will not flow through the condenser if an open exists.

In testing electrolytic condensers with d. c. be careful not to reverse their polarity. In testing electrolytic condensers with a. c. be careful to apply the current for only a second or less.

Testing Tubes

(34) Many tube testers check amplification factor and mutual conductance (these are units in which the quality of tubes is measured). Normally, however, projection room tests do not go beyond reading plate current, which procedure is explained in our discussion of amplifier circuits.

Purchasing

The projectionist sometimes does his own buying of parts and spares, but in general practice this is attended to by the manager. The projectionist, in turn, tells the manager what he needs, and often advises on matters of quality and brand. Advising the manager intelligently in such matters is a proper and very important part of the maintenance duties of the projectionist.

Stocking Parts and Supplies

(35) Good practice with respect to stocking spares requires that the resources of the projection room shall be equal to all ordinary emergencies. There should always be enough tested tubes, exciter lamps, batteries and other parts on hand to avoid delay in replacing one that is faulty. The amount of money that must be invested in such insurance comes to very little in comparison with the possible cost of a prolonged interruption or defect in the show, caused by absence of some necessary and inexpensive article. The quantity of spares needed depends largely, of course, on the distance from the source of supply, and the rapidity with which emergency orders can be filled. Remotely located theatres should not only carry a full inventory of ordinary spares, but also replacements for any supposedly permanent parts (resistors. transformers, etc.) that may have shown themselves exceptionally subject to trouble.

Selecting Parts and Supplies

(36) Except where the theatre obtains all its sound parts from one source very careful life records should be kept of every part, and compared with the purchase price. Parts of different makes should be used under identical conditions, and their life records kept and compared. There is no other way for the theatre to be sure it is getting the best value for its money.

(37) A simple bookkeeping system is necessary if such records are to be kept properly and intelligently, and are to be available when wanted. But while the projectionist can easily make the necessary entries in the proper forms or books, and doing so is a logical part of his duty, he cannot fairly be expected to design a bookkeeping system. That is the function of the management. The projectionist should, however, ask that it be done, since life records not only reduce the cost of operating the projection room, but also insure that the projectionist is supplied with parts that last longer and give him less trouble.

Keeping of such records requires that each individual part be numbered so it can be identified after weeks or months of use. Gummed labels or china-marking crayon are used for this. In parts that generate or are subjected to intense heat such markings are not permanent, and should be renewed when necessary in the course of the weekly inspection.

(38) Experience with such records will be an invaluable guide to the projectionist when he is asked to advise on the selection of a new sound system, since the cost and trouble of maintenance is as important in that selection as quality of results or initial purchase price. Some maintenance factors, for example, the rapidity with which certain parts will wear out, can only be guessed at, and guarantees should be asked to cover such points. Other maintenance factors are, however, subject to personal inspection of the equipment. The most important, perhaps, are simplicity of design and ease of accessibility, both being virtues that prevent unnecessary troubles and make those that are unavoidable easier to find.

DEFINITIONS*

There still exists considerable confusion in the matter of terms applied to various items, practices and theories in the field of projection, and it was thought best to incorporate at least a partial list of definitions. Beginners will find the following pages particularly instructive.

Absorption of Light

The retention in a transparent substance of a portion of the light energy being transmitted. It is transformed into heat.

Aberration

In a lens it may be either chromatic aberration, which in part breaks up the light into its component colors, or spherical aberration, which causes rays passing through the outer zones of a lens to focus nearer the lens than those passing through closer to its optic axis.

Acetate Film

Film, the base of which is composed chiefly of cellulose acetate.

Acetone

A liquid obtained in the process of distillation of wood alcohol. Used in film cements and for other purposes.

Actinic Rays

Light rays having the property of effecting chemical changes, especially in photographic emulsions. Usually only the green, blue, violet and ultra violet rays are regarded as actinic. However, all light rays—even the invisible ones—are actinic to some extent.

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*For definitions covering motor generator see page 295. For definitions covering optical terms see page 104.

Additive Process

Any process of color photography by means of which the colors are obtained by adding two or more of the spectral regions of which white light is composed. This may be done by use of color filters in either photography or projection. Neither the negative nor the positive print ordinarily contains color. The subtractive process is exactly the opposite, its prints carrying color from which certain filters subtract.

Air Gap

Electrically a space between magnetic or electric terminals occupied only by air.

Aerial Image

Point in the atmosphere where an image is formed by a lens system, particularly by the converging lens of a condenser.

Ampere Hour

Term employed to express the use of one ampere of current for one hour of time. Is equal to 3,600 coulombs per second.

Amplifier

An equipment used for increasing the amplitude of (a) electrical current, (b) voltage and (or) power. It is accomplished through the control by a weak power, of a greater power supplied by a different power source.

Amplifier, Audio Frequency

A device by means of which electric currents the frequency of which is in the audio-frequency range may be amplified or "built up."

Amplifier, Push-Pull

An amplifying device using two amplifying tubes, the purpose being to obtain greater amplification with less distortion.

Anode

Positive terminal of any electrical device. Cathode is the opposite or negative terminal.

Aperture, Projector

The opening in the projector aperture plate through which the picture is projected.

Arc Flame

A flame emanating from the electrode (carbon) tips of an electric arc. Has little if any value insofar as has to do with screen illumination.

Aperture Plate

A metal plate containing the aperture through which a motion picture is projected.

Armature

That part of a dynamo in which electric energy is generated, or the rotating parts of some types of motor.

Atmospheric Absorption

The absorption of light or sound energy by the air through which it passes. Air impurity increases absorption.

Attenuation

A term employed to express weakening of intensity.

Automatic Fire Shutter

A metallic blade and its operating mechanism. The blade rises from over the projector aperture when projection speed has reached a safe limit, and drops into place thus shutting off all light from the film, when projection speed drops to an unsafe level. The film must travel through the intense heat of the spot at a certain minimum of speed, else there is danger of it catching fire.

Axis, Optical

A straight line passing through the exact center of a lens, or of all elements of an optical system.

"B" Battery

A battery of comparatively high voltage used for supplying E.M.F. to the plate circuit of a vacuum tube.

Back Focus

Distance from film to the surface of the first element of a projection lens when the picture is in sharp focus on the screen and the light source a sufficient distance from the film to illuminate it with parallel rays of light. See "Working Distance."

Backlash

Lost motion. In projection applied particularly to lost motion in the projector rotating shutter.

Balsam, Canadian

A transparent balsam used in cementing elements of projection lens together.

Balanced Load

As applies to the Edison 3-wire system, an equal load between neutral and true positive and neutral and true negative.

Beam of Light

A bundle of light rays. A shaft of light having well defined outlines

Blooping Patch

A black overlay on sound track at the splices to prevent noise the splice would cause when projected were it not thus treated.

Blowing Point

Term applied to designate number of amperes of current required to melt a fuse.

Buckling or Buckled Film

Term applied when film does not lie flat over the projector aperture. May be caused by worn aperture plate and tension shoes or to new film from the hottest part of which—center of frame—the intense heat has drawn the moisture too rapidly, thus causing the film to contract unevenly.

By-Pass Condenser

A condenser employed to separate a.c. and d.c. currents in sound apparatus.

B-X

A form of flexible conduit in which insulated wires are placed for their protection.

"C" Battery

A small battery employed to supply negative potential to the grid of a vacuum tube.

Cable

Two or more insulated electric conductors bound together with heavy outer insulation. Used ordinarily in theatre and studio work for temporary conductance across floors.

Candle foot or foot candle.

A unit of illumination. The illumination power of a "standard candle" at a distance of one foot.

Candle Power

(a) Luminous power or intensity of a light source. (b) A unit of illumination equal to the illumination of a standard candle at one foot distance, which is equal to one candle meter.

Capacitance

Refers to amount or quantity of electricity a condenser is capable of holding in proportion to the voltage applied. Condenser capacity means the same thing.

Capacity, Carrying

Amount of current a conductor may carry under the rules of the Board of Underwriters.

Cathode

Negative terminal of any electric device.

Centimeter

Unit of length in metric system equal to 0.3937 of an inch.

Celluloid

A hard, transparent, flexible substance formed by dissolving camphor in alcohol and adding pyroxylin.

Change-over

In projection, the act of changing from one projector to another.

Choke Coil

See reactance coil.

Chromatic Aberration

As applied to projection, the partial separation, by lens action, of white light into its primary colors.

Circuit Breaker

An automatic switch that opens the circuit when certain dangerous conditions arise.

Circular Mil

A circle 1/1000 of an inch in diameter.

Closed Circuit

A circuit in which proper contact of parts permits current to flow.

Close-up

Picture of objects taken at very short distance. In projection usually referring to one object that fills most of the screen.

Collector Lens

Element of a condenser that is next the light source and therefore collects the light.

Cooling Plate

A shield located about one-half inch on the light source side of a motion picture projector aperture. Its purpose is to prevent the projector mechanism from being overheated.

Condenser

Optically, a lens or combination of lenses by means of which light is collected from a light source and concentrated upon the projector aperture.

Condenser

Electrically, a device usually consisting of two thin sheets of metallic substance separated by very thin insulation, the purpose being to temporarily collect and store electric energy. Its insulating medium is termed "dielectric." In certain types of condenser air supplies the insulation.

Condenser, By-Pass

See by-pass condenser.

Condenser, Stopping

A condenser employed to stop the flow of d.c. in a circuit.

Condenser, Variable

A condenser in which the capacitance may be altered, within certain limits, by the man in charge.

Conduit

Metal tubing in which two or more insulated wires are encased for their protection.

Conjugate

United in pairs. Coupled. Yoked together.

Conjugate Foci

Two foci points yoked together and controlled by a lens.

Converter

A machine in which mechanical rotation is employed to effect certain changes in electric energy. It may be used to (a) change the voltage, (b) change a.c. to d.c. or vice versa; (c) alter the phase of a.c. or (d) alter the frequency of a.c.

Coulomb

Unity of volume. Is equal to the amount, volume or quantity of electricity delivered by one ampere of current during one second of time.

Crater Angle

Angle the crater an electric arc light source makes with the optical axis of the projector lens system, or with the optical axis of a mirror collector.

Cycle

A series of operations occurring at regular intervals, as, for example, reversals of direction in a.c.

Decibel

Unit of measurement for gain and loss of energy in sound.

Dielectric

The insulation medium of an electric condenser.

Dimmer

An adjustable rheostat employed for raising or lowering the luminosity of circuits of incandescent lamps.

Diopter

Unit used by opticians to express refractive power of lenses. It is equal to the power of a lens having a focal length of one meter, or 39.39 inches.

Direct Current

(d.c.)—A current constant in flow in one direction but not necessarily constant as to voltage. Current that is constant both in voltage and direction of flow is known as continuous current.

Diffusion

As applies to projection, the reflection of light from a screen in such manner that its rays are scattered and no image is formed. Diffusion may be slight, or at very wide angles—so wide in fact that there is but a small difference in light distribution up to as much as fifty degrees.

Double Exposure

Two images photographically impressed upon a negative at separate times in such manner that both are partially visible when the resultant positive print is projected.

Dowser

In projection, a manually operated device by means of which the light may be cut off from the film and screen instantly. A metal blade that may be moved in front of the condenser at will of the projectionist.

Efficiency

Electrically, the proportion of input power that is utilized in useful work. The relation of input electric energy to the output applied usefully.

Electrodes

In arc lighting the electrodes are the carbons upon the ends of which the electric arc forms.

Electromotive Force (E.M.F.)

The force or pressure which creates and maintains an electric current in or through a conductor. It is regarded as pressure. It is measured in volts. It is abbreviated E.M.F.

Emulsion

The light-sensitive substance with which film is coated, upon which the photographic print is impressed by light action.

Exciter Lamp

Lamp supplying light to the photo-electric cell, thus creating electric currents from which sound is recreated.

Fahrenheit (F. or Fahr.)

A standard temperature scale in which 32 degrees represents the melting point of ice and 212 degrees the boiling point of water at sea level. To reduce Centigrade to Fahrenheit (C. to Fahr.) multiply degrees Centigrade by 1.8 and add 32.

Fader

Potentiometer employed to control sound volume in projection.

Fade-Away

The lowering of observed screen brilliancy when a screen is viewed at a considerable angle to its surface. Specular or semi-specular screen surfaces have heaviest fade-away; diffusive screens least.

Fade-In—Fade-Out

Gradual illumination of screen image or its gradual fading away through gradual opening or closing of lens.

Floating Battery

A battery so connected to a parallel system that the system will receive current from the battery, or the battery will be charged by the system, according to the conditions then existing.

Focus, Point of

Point of concentration. Point at which rays from a lens meet and form a sharply focused image.

Foot Candle

See candle, foot.

Frame (Noun)

Space occupied on a motion picture film by a single photograph, plus its surrounding border to center of frame lines at top and bottom.

Frame (Verb.)

Act of properly registering a film photograph over the projector aperture.

Frame Line

Opaque space between adjoining photographs on a motion picture film.

Frequency

As applies to a.c., the number of alternations per second divided by two. Number of cycles per second.

Frequency, Audio

Frequency of sound vibration within the limits of audibility.

Front Wall

As applies to projection, the wall of the projection room nearest the screen.

Gas Stream

As applied to electric arcs, a stream of incandescent gases between positive and negative carbon tips that is a high resistance conductor of current.

German Silver Wire

A wire of metallic alloy much used for purposes of resistance. It is composed of copper, zinc and nickel in varying proportions, according to the amount of resistance desired.

Graphite

One of three forms in which carbon occurs in nature. Soft graphite is a most excellent lubricant where high temperatures exist.

Grid

As applied to resistance. one of the resistance elements of a certain type of rheostat. As applied to sound apparatus, the element located between filament and plate in vacuum tubes.

Grid Leak

A very high, non-inductive resistance frequently connected in the grid circuit of a 3-element vacuum tube.

Ground

A term employed to designate an unintended connection between polarities, the same having too high resistance to constitute a short circuit. A connection of one or both polarities with earth. An electric contact of one polarity with some substance not ordinarily considered as a conductor, which is sometimes made to serve as one side of a circuit.

Ground Noise

Unintended noise in sound reproduction and projection. May be due to many causes.

Ground Wire

A wire connecting one wire of an electric circuit with earth. A wire connecting some part of an electric equipment not supposed to be charged, with earth.

Hot Wire

A charged wire—particularly if at high voltage.

Horse Power

Unit power equaling the expenditure of 33,000 foot pounds per minute. In theory it represents the power exerted by a horse pulling at full strength on a gear-down that will, at walking speed, raise a 33,000 pound weight 12 inches in one minute of time.

Image, Screen

The image formed by rays from the projection lens upon the screen.

Image, Aerial

Point in a projected light beam where if a screen be interposed, an image will be formed, as the aerial image of a projector converging lens.

Induction

The influence exerted either by magnetic fields upon other magnetic fields or by magnetic fields upon current.

Induction Motor

An alternating current motor the currents for which are led through the field coils only, and not being connected with the outside circuit, the armature receives its torque impulses from currents induced by the varying field set up by the field coils. In such motors the rotating part is termed the "rotor"; the stationary part is the "stator."

Insulating Materials

Materials that are very poor conductors of electricity (there is no complete insulation). Of the much used materials the following are among the best. Glass. Mica. Shellac, Porcelain. Slate. Marble and various manufactured products.

Insulation

Use of substances having high electrical resistance to confine electric current to its appointed path.

Insulating Tape

A cloth tape impregnated with insulating compound, usually tar and resin in about the proportions of 30 to 40. It is both insulating and adhesive.

Intermittent Movement

The mechanism by means of which motion is imparted to the intermittent sprocket of a motion picture projector.

Intermittent Sprocket

Motion picture projector sprocket that imparts movement to the film between the upper and lower loops.

Ionization

A phenomenon that enables gas to become a conductor of electricity.

Iris

An adjustable diaphragm by means of which an opening may be gradually reduced in area, closed or expanded.

Kilocycle

One thousand cycles.

Kilometer

One thousand meters. 3,281 feet. 0.62138 of a mile.

Kilowatt

One thousand watts.

Kilowatt Hour

One kilowatt used for one hour.

Knife Switch

Switch having a copper blade hinged at one end and having compression contact with copper clips at the other, such contact completing a circuit.

Lamphouse

Metal housing by which the projector light source is enclosed.

Leader

A suitable length of preferably opaque film attached to each reel of film ahead of its title to permit threading the projector without making use of either title or subject matter. The standard release print constitutes the leader in present practice.

Lens Port

Opening in projection room front wall through which light from the projection lens passes.

Loop

In projection, the curves of slack film by means of which the film between them is enabled to move intermittently whereas film above and below it runs continuously. The upper loop is between the upper sprocket and aperture plate; the lower loop between the intermittent sprocket and lower sprocket.

Mains

Term commonly used to designate the principle distributing circuits of an electric system, as, for example, the street mains.

Mat, Slide

A paper mat that outlines or borders the photograph on a stereopticon slide.

Magazine

Metal compartments of a projector in which the reels of film are enclosed during the process of projection.

Magazine Valve Fire Trap

A device having two metal rollers located close together, between which the film enters the projector magazine. The rollers hug the film so closely that fire cannot pass.

Magniscope

A special wide angle lens by means of which special screens may be projected in huge enlargement.

Magnet, Permanent

~~Soft iron~~ impregnated with magnetism which it retains constantly, in contradistinction to an electric magnet that looses its magnetism when not in active use.

Magnetic Field

Region surrounding the poles of a magnet through which flow lines of magnetic force. Strongest in proximity to the poles, weakening rapidly as distance therefrom is increased.

Magneto

A device for generating electricity by electro-magnetic induction. It consists of a permanent magnet and an armature rotated by a hand crank. Excellent for testing for grounds.

Master Blade

Blade of projector rotating shutter that covers the lens while the intermittent sprocket is in motion.

Mean Spherical Candle Power

Average spherical candle power.

Meter

(a) An instrument employed for measuring substances or those used to measure elements constituting electric power. (b) A unit of length in the metric system equaling 39.37 inches.

Mica

A natural mineral substance that may be split into very thin sheets by natural cleavage. It has an electrical resistance of 84,000,000,000,000 ohms per cubic centimeter when pure. Not affected by high temperatures, hence much used for arc lamp insulation.

Mil

A unit of length equal to 1/1000 of an inch. Employed for measuring electric conductors.

Mil Foot Standard of Resistance

Standard unit for measurement of resistance. It is the resistance offered by a wire one mil in diameter by one foot in length made when the wire is at normal temperature. For commercial copper it amounts to 10.50 ohms per mil foot.

Millimeter

Unit of length equaling 0.03937 of an inch. Usually expressed as mm, m.m. or m/m.

Misframe

(a) An improperly made splice in which two adjoining frames are not present in their entirety. (b) Picture not in proper register over the projector aperture.

Monitor Horn

A loud speaker installed in the projection room.

Multi Phase

Term applied to systems having two or more current phases coupled together. "Polyphase" is the term more commonly applied.

National Electric Code

A book of rules and regulations* established by the National Board of Fire Underwriters for electric wiring and apparatus.

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*A copy should be in the library of every projectionist. It may be had by addressing the National Board of Fire Underwriters, Electrical Department, 85 John Street, New York City, New York. Enclose ten cents in stamps to cover postage.

Negative

Film developed after exposure in a camera. Its lights are dark and its darks light, as compared with the positive.

Negative Carbon

In d.c. lamps the carbon connected to the negative side of the circuit. In a.c. lamps each carbon is alternately negative and positive.

Negative Wire

Wire attached to negative side of the power source.

Neutral Wire

The central wire in a 3-wire system. It is negative to one outside wire—the true positive; and positive to the other—the true negative.

Neutral Ammeter

An ammeter connected into the neutral wire to enable those in charge to know how nearly the load is in balance.

Nickel Steel

Ordinary soft steel to which a small percentage of nickel has been added. About 3.25 percent of nickel gives best results.

Observation Port

Opening in wall through which the projectionist observes the screen.

Ohm

The unit of electrical resistance.

Oil Well

In a projector, an oil tight casing containing the intermittent movement, together with sufficient oil for its adequate lubrication. In a motor or generator, a depression in the metal immediately under each bearing, designed to contain sufficient oil for adequate lubrication of the bearing.

Open Circuit

An electrical circuit which is not complete, either by reason of an open switch or by some fault, as a broken wire.

Optical Train

In a motion picture projector those various optical elements by means of which the light is collected, its course diverted and finally sent forward to the screen. It is comprised of collector, converger and projection lens.

Outlet

Electrically, a point out of which circuit wires are led for attachment to various power using devices.

Outlet Box

A metal box located at an outlet where it serves the double purpose of anchorage and protection.

Output

Electrically, energy, measured in watts, delivered by a power circuit, dynamo, motor or battery, etcetera.

Outside Transformer

As applies to theatres, a transformer outside the building through which current is supplied to the theatre.

Overload

A load of greater amount than a circuit or an equipment is designed to carry or produce.

Overload Capacity

The amount of overload an equipment may carry, either permanently or temporarily, without sustaining injury other than increased rapidity of deterioration.

Over-Shooting

When by reason of insufficient tension the film at a projector aperture moves too far, it is said to be "over-shooting."

Panel Board

Name applied to a small distributing switchboard.

Parallel or Multiple Connection

The two terms mean the same thing. It means so connecting two or more equipments that in a direct current circuit, all positive poles are connected to the positive side and all negative poles to the negative side, or in an a.c. circuit, so connecting them that one circuit wire connects to one side of all the equipment and the other wire to the other side of all equipment. This applies to generators, motors and rheostats. In fact to any equipment. By such a connection the full amperage output of each such equipment is delivered to the circuit being supplied.

Perforations

Holes on either side of the film with which the sprocket teeth engage to impart motion to the film. There are eight to each frame—four on either side.

Permeability

(a) Susceptability of a substance, usually iron, to magnetization. (b) Ratio between number of lines of force per unit area passing through a substance that can be magnetized and the force that produces the said lines. (c) Ease with which magnetic lines of force penetrate or pass through any substance. Permeability of good, soft iron is approximately 3000 times that of air, though it may vary widely according to conditions in both mediums.

Perpendicular

In optics, at right angles to any given line or plane.

Phase Splitter

A device by means of which two currents may be produced from a single phase current—the currents differing in phase.

Phase

In vibratory or wave motion a phase is that portion of any complete movement, either in angle or in time, that any moving point has executed.

Phosphor Bronze

An alloy of copper and tin to which 2 to 5 percent of phosphorous has been added.

Polarity Switch

A double-pole, double-throw switch so wired that reversing its position ("throwing it over") reverses the polarity of the circuit it controls.

Photo Electric Cell

Some chemical elements throw off electrons when exposed to light, the amount thus emitted depending exactly upon the intensity of incident light at any instant of time. This has the effect of transforming light into electric energy of strength proportional to the intensity of the light that produced it. A photo electric cell contains a surface of such elements and a positively charged electrode which attracts to it the electrons emitted or thrown off.

Photo-Electric Cell Amplifier

The amplifier that provides first amplification to the enormously weak currents set up in the photo-electric cell.

Photometer

Any device used for measuring light intensity.

Picture Cycle

Term applied to the entire series of operations as between the placement of one frame of film over the projector aperture and the placement of the next succeeding frame.

Potential

Voltage or level of electric pressure in volts.

Potential Difference

The drop in pressure across current-using equipment that produces power.

Projection Lens

The compound lens by means of which the screen image is projected.

Projection Room

The enclosure housing the projector apparatus. The room from which motion pictures are projected.

Polyphase Current

Any current having more than two phases.

Port

In projection, an opening in the front wall of the projection room through which a light beam passes or the screen is observed.

Positive Brush

The d.c. dynamo or motor brush connected to the positive side of the circuit or system being served.

Positive Carbon

In projection, the d.c. arc lamp carbon attached to the positive side. The carbon on which the crater forms. In an a.c. arc each carbon is alternately positive and negative many times a second, hence a crater forms on each carbon.

Positive Pole

Pole of dynamo, battery or motor to which positive side of system being served is connected. With a.c. each pole is alternately positive and negative.

Power Applied

Rate at which work is done. Work divided by the time in which it is accomplished.

Primary Coil

In a transformer, the coil to which the power source is connected. Consists of insulated wire in close proximity to or wound upon a laminated iron core.

Primary Current

Current applied to the primary coil of a transformer.

Print

Term applied to positive film printed from a negative. The film used in projection.

Projection Angle

Angle the axis of the light beam makes with a line perpendicular (at right angles with) to the screen surface.

Projection Distance

Distance from projection lens to center of screen.

Projection Speed

Speed, in feet per minute, at which film passes through a projector.

Projectionist

A person who makes the projection of motion pictures and sound his profession.

Projector, Motion Picture

The combination of mechanical, electric and optical set-up by means of which motion pictures are projected. It also includes a portion of the sound reproduction and projection equipment.

Push Button

A single-pole, spring-controlled contact switch manually operated by pushing on a "button."

Quick-Breaking Switch

A switch which breaks contact very suddenly by reason of spring action.

Racing

As applied to a motor or generator, an acceleration of speed when suddenly relieved of all or a portion of its load.

Radius

Half the diameter of a circle.

Rain

Term applied to an effect on the screen caused by scratches on the film that have filled with dirt and are therefore either partly or wholly opaque.

Ratio of Intermittent Movement

Ratio of time intermittent star and sprocket are in motion to time they are at rest during each cycle of intermittent action.

Ratio of Transformation

In a transformer, the ratio of primary to secondary voltage. It is expressed: as number of turns in primary coil are to number of turns in secondary coil, so is primary voltage to secondary voltage.

Reactance Coil

Same as choke coil. A coil of insulated wire wound around a suitable iron core for the purpose of providing induction with low resistance. Used to control a.c. current with small power loss. Also know as "impedance coil."

Reel

A flanged spool of metal upon which film is wound both for its protection and convenience in handling.

Reel of Film

Term applied to footage of film carried on a reel when it is approximately full.

Reflection

As applied to light or sound, the throwing back of such portion of the energy (waves) as is not absorbed by or which cannot enter the substance which they contact.

Reflector Type Light Source

In projection, a light source having a horizontal positive carbon and either a horizontal negative carbon or one more or less inclined from the horizontal, its light source (crater) facing away from the projector aperture and toward a curved mirror, which latter collects the light and reflects it back to the aperture.

Refraction

In projection, the bending of light rays by lens action.

Refractive Index

When light rays pass from one transparent medium to another transparent medium of different density and do so at an angle, the ratio of the angle of incidence to the angle of refraction is known as the "refractive index" or "index of refraction" of the second medium with respect to the first.

Remote Control

Control of apparatus from a location removed therefrom, usually by electrical means.

Residual Magnetism

The magnetism retained by a permanent magnet when it is not in use.

Resistance

(a) As applied to electricity, that property of a conductor that opposes current flow. (b) The term often applied to a rheostat.

Resistance Coil

A coil of wire of the kind used for resistance. For example, a rheostat coil is a "resistance coil."

Resistance Losses

Loss in voltage encountered in forcing current through conductors.

Resistance of the Arc, or Arc Resistance

Resistance the current encounters in passing from one carbon tip to the other in an electric arc.

Resistance Wire

A wire of metallic alloy calculated to offer a predetermined, fixed amount of resistance per unit of length to current flow.

Reverberation

Persistance of sound in an enclosed space. It is due to sound reflected by enclosing surfaces.

Rewinder

A mechanical device by means of which films may be transferred from one reel to another in the process of reversing the positions of beginning and ending of the film.

Rewinding

Process of transferring film from one reel to another, reversing the positions of the two ends of the film.

Rheostat

A device consisting of units of resistance so connected that the current must pass through the entire length of each such unit, and through them all successively, unless otherwise provided.

Fixed Resistance

A rheostat in which the current must pass successively through all resistance elements therein contained.

Resistance, Adjustable

A rheostat having means provided for adding to or subtracting from the number or numbers of the resistance elements in use at will of the projectionist.

Ring, Oiling

Pertains to a method of oiling machinery bearings. A metal ring of larger diameter than the shaft to be lubricated is hung on the shaft and able to rotate therewith, passing through a slot in the bearing. This ring, being of much larger diameter than the shaft, hangs down below it into a depression in the bearing support that is filled with oil. As the ring rotates oil is carried up to the bearing, where it is distributed by means of spiral slots cut in the bearings.

Rocker Arm

That part of a dynamo or motor to which the brush holders are attached.

Rotary Converter

A dynamo for generating both A.C. and D.C. If conductors are let from the armature of a D.C. dynamo to the collector rings of a rotary converter, A.C. may be obtained. If the machine is run as a D.C. motor, A.C. may be taken from the collector rings. If run as a synchronous A.C. motor, D.C. will be delivered by the commutator. The machine also is defined as a rotary transformer.

Rotary Field

The magnetic field created by a combination of alternating currents differing in phase. If an armature having suitable windings is rotated therein, the field itself will rotate by reason of induced currents. The action of induction motors is dependent upon a rotary field.

Rotor

In a dynamo or motor, the part that rotates. In an induction motor the "rotor" usually is the armature, the other part the "stator."

R.P.M. or RPM

Abbreviation for revolutions per minute.

R.C.

Abbreviation for rubber-covered.

Saturation, Point of

As applies to magnets, the highest power to which the magnetic field can be raised. As applies to liquids, the point at which it will absorb no more of some given substance soluble therein.

Screen

In projection, the surface upon which the projected rays of light are focused and the image formed.

Screen, Diffusive

A screen the surface of which scatters the reflected light rays widely.

Screen, Semi-Diffusive

A screen the surface of which scatters the reflected rays in more narrow angles than does the diffusive surface, and in somewhat wider angles than does the specular surface.

Screen, Specular

A screen surface having relatively slight powers of diffusion. Heavy fade-away occurs after the 20 degree viewing angle is passed.

Screen, Brilliancy

(a) Brilliancy of screen surface as measured in foot-candles by a photometer. (b) Apparent brilliancy of screen as viewed from the auditorium.

Screen Setting

Immediate surroundings of the screen.

Secondary Coil

In a transformer, the coil that delivers secondary current.

Secondary Current

The current induced in the secondary coil of a transformer. The current delivered by a transformer.

Secondary E.M.F.

The power induced in a secondary transformer coil.

Self Contained

Term used to designate a machine all the essential parts of which are attached to one frame or carried on one foundation.

Self Oiling Bearings

Machine bearings that are oiled by some action of the machine itself.

Series

As applied to electrical equipment, lamps, etc., a connection so made that the current must pass successively through two or more of the devices so connected.

Series Wound Dynamo

One in which all current generated passes through the coils of the field magnet.

Series Shunt Dynamo

A dynamo, the field coils of which are wound with both shunt coils and a series winding.

Series-Parallel Connection

Two or more groups of current using devices connected in parallel, with the said groups connected in series with each other. Seldom used today.

Series Wound Motor

A motor wound the same as a series wound dynamo insofar as has to do with field coils.

Shellac

A resinous varnish the liquid component of which is alcohol. In certain classes of work it is used for insulation purposes.

Short Circuit

In common acceptance of the term, a fault in an electric circuit or piece of electrical equipment which enables the current to flow through an unintended path to opposite polarity with little or no resistance.

Shunt

In an electrical circuit, a by-path over which a portion of the current may pass.

Shunt Coil

A coil connected in parallel so as to form a shunt to the main circuit.

Shunt Wound Dynamo

A dynamo having its field coil connected in shunt to the main circuit. See Fig. 3.

Shunt Wound Motor

A motor the field winding of which is connected in shunt to the main armature circuit.

Single Pole Switch

A switch that has but one contact and controls but one wire of a circuit.

Solid Carbon

A carbon having no core.

Sound Gate

Part of sound head that holds film in proper position so that sound track will pass over sound aperture correctly.

Sound Head

That portion of motion picture projector containing the exciter lamp, the optical system, the photo cell and the mechanism controlling movement of film.

Sound Track

Space on film upon which sound is photographically impressed.

Speed Indicator

An instrument used to determine speed, usually of rotation.

Spherical Aberration

That quality of an uncorrected lens that causes rays of light passing through at varying distances from its optical axis to focus at different distance from its optical center, those nearer its outer margins focusing closer to the lens.

Spherical Candle Power

Candle power of a light source measured in every direction.

Splicing

Joining two sections of a film together.

Split Phase

A single phase current divided into poly-phase current by means of a phase splitting device.

Spot

(a) Spot of light on projector cooling plate. (b) Contraction of spotlight.

Sprocket

A rotating metal cylinder on each side of which are teeth by means of which film is caused to pass through projectors, cameras, etc.

Split-Phase Motor

A single induction motor equipped with a phase splitting device to enable its starting.

Standard Candle

See Candle, Standard.

Standard Film

Film of the dimensions established by the Society of Motion Picture Engineers. One is 35 and one is 16 mm wide.

Star

As applied to projection, the member of the motion picture projector intermittent movement mounted on the same shaft with and imparting motion to the intermittent sprocket.

Steel

A compound of iron, a small percentage of carbon and usually a small perecntage of silicon and manganese. It is the carbon that causes the metal to harden when cooled suddenly from red heat; and to soften again when cooled slowly.

Step-down Transformer

A transformer that delivers secondary current of higher amperage and less voltage than that of the primary.

Step-up Transformer

A transformer that delivers secondary current of higher voltage and less amperage than the primary.

Stereopticon

An equipment for the projection of still pictures.

Stereopticon, Dissolving

Two complete stereopticons so joined that the screen image being projected by one may be dissolved or faded out by a picture projected by the other.

Stopping Down

In projection the act of reducing a lens diameter by means of a mask or its equivalent.

Storage Battery

A form of battery the elements of which when subjected to the action of electric current undergo certain chemical changes creating a condition enabling them, by chemical action, to produce electric power in proportion to the energy consumed in affecting the change, minus some loss incident to the operation. Such a battery does not "store" electricity. It merely, due to the change above described, has power to produce E.M.F.

Stranded Wire

An insulated conductor made up of several small copper wires, usually twisted together.

Stranded Wire, Asbestos Covered

An asbestos insulated conductor made up of fine copper wires, usually either No. 30 or 31, designed for use where temperatures are high and considerable flexibility is necessary.

Synchronism

As applied to a.c. generators, the time relation existing between two or more alternators with relation to the pressure waves generated by them.

Synchronizing Generators

Such regulation of two or more alternators connected in parallel as will cause the pressure waves generated to be identical in frequency, and to be in phase.

Synchronous

Corresponding exactly in time.

Synchronous Motor

An a.c. motor that must be brought up to normal speed of operation by a split phase or other means before being connected to the power circuit. It then runs "in step" with the alternations of the current driving it.

Take-up

A variable tension device by means of which film is wound upon the lower or take-up reel of a motion picture projector.

Tension

As applied to projectors, (a) frictional pressure exerted upon the film at the aperture to bring successive pictures to a stop over said aperture. (b) Tension exerted by some suitable device upon the shaft carrying the lower or take-up reel of a projector. It must be such as will provide slippage to enable the lower reel to rotate at varying speed, gradually slowing up as diameter of film roll increases during the process of projection.

Tension Shoes

Metal bars bearing upon the film at the projector aperture, upon which the tension springs exert pressure.

Tension Springs

Springs exerting pressure upon the tension shoes.

Three-Phase Current

An alternating current in which three pressure waves or electro motive forces are exactly 120 degrees apart.

Throw

See Projection Distance.

Torque

Pulling force which tends to create rotary motion, as in the rotor of an electric motor.

Trailer

A short length of film, usually opaque, attached to the end of each reel of film to protect it from damage.

Transformer

A device for efficiently alternating a.c. voltage and amperage by means of magnetive induction.

Transformer Loss

The loss inherent in transformers should be less than ten per cent.

Traveling Arc

An unsteady electric arc in which the point of highest luminosity moves about.

T.P.S.T. Switch

A triple pole, single throw switch. It has three blades and makes or breaks on one set of contacts only.

Two-phase Current

An E.M.F. in which the two current waves differ by 90 degrees.

Ultra Violet Waves

Light rays existing beyond the visible spectrum. Such rays are said to vibrate in excess of 800 billion times per second. They are effective in photography.

Unbalanced Load

As applied to a 3-wire circuit, a condition in which more power is being taken from neutral and true positive than from neutral and true negative, or vice versa. Has the effect of loading one generator more heavily than the other.

Underwriters' Rules

See "National Electrical Code."

Useful Life

Term applied to length of life equipment may attain without too much loss in efficiency, either in operation, upkeep or by comparison with later, more improved equipment.

Volatilization

In projection, the transforming of carbon into vapor through the action of heat.

Volt

The unit of electric pressure.

Volt Meter

An instrument for measuring voltage. It is connected across the circuit to be measured—to both wires.

Watt

The practical unit of electric power. Equals product of volts and amperes.

Watt-Hour

Energy consumed when one watt of electric power is used for the space of one hour.

Watts Per Candle Power

The specified power consumption of an electric light source is watts of power consumed per mean spherical candle power of illumination produced. The candle power produced per watt of electric energy applied.

Wire Gauge

A gauge used for measuring wire diameters according to an arbitrary standard. The measurement is in mils. The Brown and Sharpe gauge is standard for the United States. It is also known as the U. S. wire gauge.

Working Aperture

In projection, that portion of a lens diameter actually in use.

Working Distance

Distance from emulsion surface of film in a motion picture projector to nearest surface of projection lens when said lens is adjusted to produce the finest possible definition in the screen image. See Back Focus.

MATHEMATICAL TERMS

Following are mathematical terms frequently used in technical operations and important enough to be given definitions in this volume.

An *Integer* is a number that represents whole things. A whole number in contradistinction to a fraction.

An *Abstract Number* is a number that does not refer to any particular object.

A *Concrete Number* is one employed to designate objects or quantities.

Factors of a number are numbers which, multiplied by themselves equal that number, as 2 and 3 are factors of 6 because $2 \times 3 = 6$.

A *Multiple* of a number is any number exactly divisible by that number, as 4 is a multiple of 2 because 4 is divisible by 2 without a fraction.

To *square* any number it is only necessary to multiply it by itself, as $5 \times 5 = 25$, which latter is the square of 5.

To *cube* any number, multiply it by itself and that result again by the number, as $3 \times 3 = 9$ and $9 \times 3 = 27$. 27 is the cube of 3.

Rule of Three. The old "rule of three" is often a very convenient medium for solving problems in proportion, as, if ten items cost six dollars, how much would four similar items cost? Once understood the rule may be applied in many ways. It works as follows: Suppose 30 cubic inches of iron weigh 8 pounds and you wish to know how much 378 cubic inches of the same kind of iron would weigh. This it is evident is a case of direct proportion in which the required answer in pounds will exceed the number stated, namely, 8. We state the problem thus 30 : 8 :: 378 : required answer. This is read as follows: As 30 is to 8 so will be 378 to the required answer. We therefore multiply one of the inner amounts by the other (378 × 8) and divide the result by the outer number, thus: 378 ×8 = 3,024 ÷ 30 = 100 3/5 pounds, the answer.

It is always the same, except that in inverse proportion where the required amount will be smaller than the stated amount: in the above case if we wish to ascertain the weight of 20 pounds, knowing the weight of 30, we then would place the smaller number first, thus, 8 : 30 :: 20 : the required answer, which figures out 30 × 20 = 600 and 600 ÷ 8 = 75. You may often find this rule very convenient.

The Positive-Negative Test

At times it may be necessary or convenient to determine which is the positive of a DC circuit before making final connections. One accurate simple test is to cut an ordinary potato in half—a large one if the voltage be 220—and thrust the wire ends into it the following distances apart:

1 to 3 volts,	¼ of an inch.
3 to 15 volts,	⅜ of an inch.
15 to 50 volts,	½ of an inch.
50 to 110 volts,	1 inch.
110 to 220 volts,	1½ inches.

These distances are not intended to be exact, but are efficient for the purpose. When all is readiness close the switch. Soon bubbles will form around the negative, and if the wires are copper, the totato will be stained green around the positive. With low voltages it may require several minutes to get up the effect.

USEFUL EQUIVALENTS

Meters × 39.37 = inches.
Meters × 3.281 = feet.
Kilometers × 0.621 = miles.
Kilometers × 3.281 = feet.
Centimeters × .3937 = inches.
Millimeters × .03937 = inches.
Watts ÷ 746 = horsepower.
Kilowatts × 1.34 = horsepower.

PROTECTIVE LEADER

Either transparent or raw stock.

When the protective leader has been reduced to a length of four feet it is to be restored to a length of six feet.

IDENTIFICATION LEADER (Part Title)

Shall contain 24 frames in each of which is plainly printed in black letters on white background: (a) type of print, (b) part number (Arabic numeral not less than ¼ of frame height), and (c) picture title.

SYNCHRONIZING LEADER

Shall consist of 20 frames ahead of Start mark, then 12 feet, including Start mark, to picture, opaque except as specified below:

In the center of the first frame there shall be printed across the picture and sound track area a white line 1/32 inch wide upon which is superimposed a diamond ⅛ inch high.

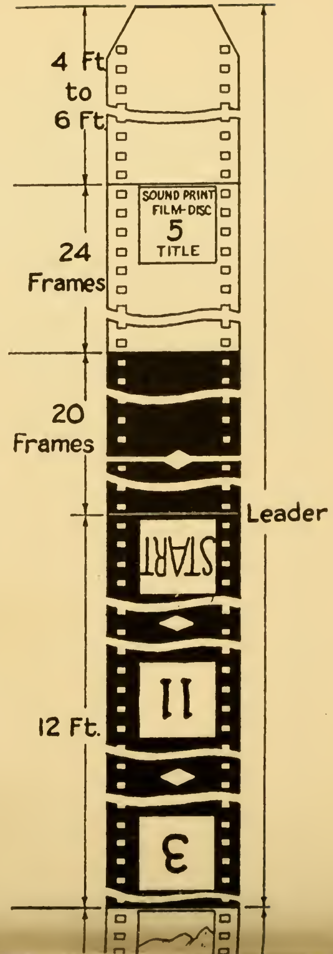
The next 15 frames may be used by the studio for sensitometric or other information. If not so used this leader shall be opaque.

The Start mark shall be the 21st frame, in which is printed START (inverted) in black letters on white background. The Academy camera aperture height of .631 inch shall be used in the photography of this frame, and all others between Start mark and beginning of picture.

From the Start mark to the picture the leader shall contain frame lines which do not cross sound track area.

Beginning 3 feet from the first frame of picture, each foot is to be plainly marked by a transparent frame containing an inverted black numeral at least ½ frame height. Footage indicator numerals shall run consecutively from 3 to 11, inclusive.

At a point exactly 20 frames ahead of the center of each footage numeral frame there shall be a diamond (white on black background) ⅛ by ⅜ inch wide.



MOTOR CUE

Shall be circular opaque marks with transparent outline printed from the negative which has had four consecutive frames punched with a serrated edge die .094 inch in diameter. The center of these holes is to be halfway between the top and second sprocket holes .281 inch from the righthand edge of the film with heads up and emulsion toward the observer.

Following the four frames containing the circular opaque marks there shall be ten feet twelve frames to the beginning of the change-over cue.

CHANGE-OVER CUE

Four frames containing circular opaque marks, punched similarly to and of the same dimension and position on the frame as the motor cue.

Following the change-over cue marks there shall be eighteen frames to the beginning of the runout trailer.

RUNOUT TRAILER

Shall be opaque, 3 feet in length.

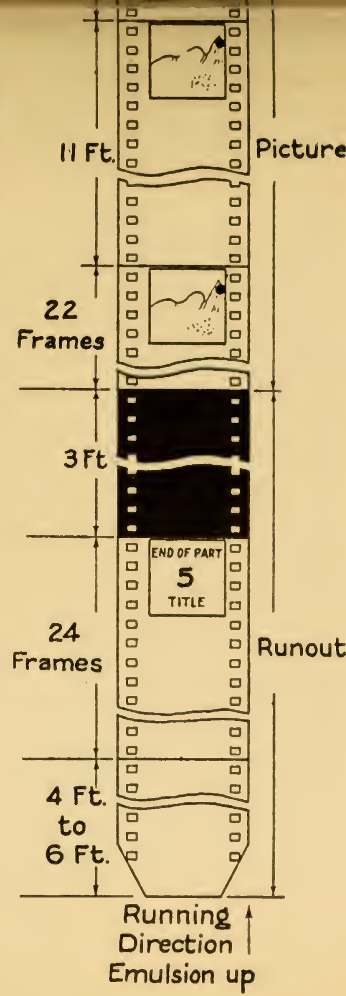
IDENTIFICATION TRAILER (End-of-part Title)

Shall contain 24 frames in each of which is plainly printed in black letters on white background: (a) "End of Part," (b) part number (Arabic numeral not less than ¼ of frame height), and (c) picture title.

PROTECTIVE TRAILER

Same as protective leader.

(7th revision 5/1/34.)



The area of a circle is equal to the square of its radius (half its diameter) multiplied by 3.1416, or to the square of its diameter multiplied by 0.7854.

Regardless of its size every circle is divided into 360 degrees, hence the width or length of one degree of any circle is equal to its circumference divided by 360.

The diagonal of any square is equal to one of its sides divided by 1.4142.

Fractions

It very often is necessary to add, subtract, multiply or divide common fractions. Rare necessity for them makes one frequently unfamiliar in an emergency. The operations are as follows:

To add two fractions, as 1/2 plus 1/3, it is first necessary to reduce them to a "common denominator," which is done by multiplying both the numerator and denominator of each fraction by the denominator of the other fraction, thus:

$$\left(\frac{1\times 3}{2\times 3}=3/6\right)$$

and 1/3 multiplied in the same manner by 2, the denominator of the other fraction equals 2/6

$$\left(\frac{1\times 2}{3\times 2}=\frac{2}{6}\right)$$

and

$$2/6+3/6=5/6.$$

Any two fractions may be added in this way.

To subtract one common fraction from another, proceed in exactly the same way as in addition, except that you subtract the smaller numerator from the larger, after having reduced them to a common denominator of course.

To multiply two common fractions, you merely multiply one numerator by the other and one denominator by the other, thus:

$$\frac{1}{2}\times\frac{1}{4}\text{ equals }\frac{1\times 1}{2\times 4}=\frac{1}{8}.$$

To multiply a common fraction by a whole number it is only necessary to multiply the numerator or divide the denominator by the whole number, thus:

$$\frac{1}{2} \times 2 = \frac{1 \times 2}{2} \text{ or else } \frac{1}{2 \div 2}.$$

In either case the answer is 1.

To divide one common fraction by another you merely invert the divisor and proceed as in multiplication, thus:

$$\frac{1}{2} \div \frac{1}{4} = \frac{1}{2} \div \frac{4}{1} = \frac{1 \times 4}{2 \times 1} = \frac{4}{2} \text{ or } 2.$$

To divide a common fraction by a whole number it is only necessary to multiply the denominator or divide the numerator by the whole number.

Formulas, Symbols and Their Meanings

A formula is what corresponds to the stenographer's "shorthand." We can say that

area equals length time breadth

is a formula. But if it is necessary to do that with a considerable number of formulas they would occupy a lot of space and require too much time and energy in their writing down. We therefore, to avoid this, make them shorter by employing symbols in the place of words.

A "symbol" is any sign, mark or letter employed to express or represent some certain thing in a "shorthand" manner. The word area begins with *a*. We therefore may, with consistency, let *a* represent (be a symbol for) the word area. In like manner we may use "l" to represent length and "b" for *breadth*. We may go further, and in common practice we do, use = as the symbol for *equals* and × as representing *times* or *multiplied by*. Our formula, thus symbolized, becomes

$$a = l \times b$$

which reads, in words, area equals length multiplied by breadth. We thus see the large saving in space made possible by using symbols.

However, since all mathematicians have agreed to do so, the formula is usually still further shortened by omitting the ×, it being generally understood that where two symbols are next to each other, without any sign between, they are to be multiplied. Thus

$$a = lb$$

is read *a* equals length multiplied by breadth, the × being assumed.

Often it is necessary or desirable to express so many ideas or problems symbolically that the English alphabet does not contain enough letters to serve without confusion. Recourse then is had to other alphabets, notably the Greek. If it were for any reason desirable the foregoing formula might be written as

$$\alpha = \lambda\beta$$

In fact any symbol may be selected to represent any quantity or thing, but as a rule certain symbols are universally used to represent certain things. This is necessary so that when mathematicians or engineers discuss problems in print each may know what the other is talking about without in each case reading a glossary of symbols. Therefore by nutual agreement certain symbols represent certain things. For example, *I* represents current flow in amperes; *g* the gravitation of the earth, and so on. Take note that often the symbol is not the first letter of the word it may represent, as *I*, in the case of current. There usually is a history connected with the choice of letters or symbols, but so long as their meaning is understood, the story is irrelevant.

In mensuration or geometry, the Greek letter π (pronounced as *pie*) stands for the number 3.1416, by which the diameter of a circle must be multiplied to ascertain its circumference. Therefore if *c* stands for circumference and *d* for diameter, then the relation of diameter to circumference is expressed as

$$c = \pi d.$$

which of course means circumference equals 3.1416 times the diameter.

A few other symbols in common use, and their meanings, are

λ, wave length.
M, amplification constant of electron tubes.
e, electromotive force.
f, frequency.

The advantages of symbolic expressions justifies the trouble of making oneself familiar with those frequently employed in text books and other reading material dealing with projection. Once the meaning of the symbols is understood, the formulas are not at all difficult of understanding.

DECIMAL EQUIVALENTS

1/64......	.015625	33/64......	.515625
1/32......	.03125	17/32......	.53125
3/64......	.046875	35/64......	.546875
1/16......	.0625	9/16......	.5625
5/64......	.078125	37/64......	.578125
3/32......	.09375	19/32......	.59375
7/64......	.109375	39/64......	.609375
1/8	.125	5/8	.625
9/64......	.140625	41/64......	.640625
5/32......	.15625	21/32......	.65625
11/64......	.171875	43/64......	.671875
3/16......	.1875	11/16......	.6875
13/64......	.203125	45/64......	.703125
7/32......	.21875	23/32......	.71875
15/64......	.234375	47/64......	.734375
1/4	.25	3/4	.75
17/64......	.265625	49/64......	.765625
9/32......	.28125	25/32......	.78125
19/64......	.296875	51/64......	.796875
5/16......	.3125	13/16......	.8125
21/64......	.328125	53/64......	.828125
11/32......	.34375	27/32......	.84375
23/64......	.359375	55/64......	.859375
3/8	.375	7/8	.875
25/64......	.390625	57/64......	.890625
13/32......	.40625	29/32......	.90625
27/64......	.421875	59/64......	.921875
7/16......	.4375	15/16......	.9375
29/64......	.453125	61/64......	.953125
15/32......	.46875	31/32......	.96875
31/64......	.484375	63/64......	.984375
1/2	.5	1.	1.

GEOMETRIC CONSTANTS

Circumference	$= \text{Diameter} \times 3.1416$
Circumference	$= \text{Radius} \times 6.2832$
Radius	$= \text{Circumference} \div 6.2832$
Radius	$= \sqrt{\text{Area} \div 3.1416}$
Radius	$= \sqrt{\text{Area} \times 0.5642}$
Diameter	$= \text{Circumference} \div 3.1416$
Diameter	$= \text{Circumference} \times 0.3183$
Diameter	$= \sqrt{\text{Area} \times 1.1284}$
Diameter	$= \sqrt{\text{Area} \div 0.7854}$
Area	$= \text{Square of radius} \times 3.1416$
Area	$= \text{Square of diameter} \times 0.7854$

CENTIGRADE AND FAHRENHEIT SCALES

Centigrade	Fahrenheit	Centigrade	Fahrenheit
0	32	50	122
5	41	55	131
10	50	60	140
15	59	65	149
20	68	70	158
25	77	75	167
30	86	80	176
35	95	85	185
38	100.4	90	194
40	104	95	203
42	107.6	100	212
45	113		

MELTING POINT OF MATERIALS

	Fahrenheit		Fahrenheit
Mercury	—39	Bronze	1,692
Tin	442	Silver	1,873
Bismuth	507	Copper	1,996
Lead	617	Gold	2,016
Zinc	773	Cast Iron, Gray	2,786
Antimony	1,150	Steel	2,372 to 2,552
Aluminum	1,157		

TABLE OF REFLECTION POWERS BY DIFFERENT SURFACES

This table should be of value to those selecting theatre interior decorations. The percentages indicate the proportion of the total light falling upon the various surfaces which is reflected.

Material	Per cent.	Material	Per cent.
Polished silver	92 to 93	Yellow cardboard	30
Mirror silvered on back	82 to 88	Light blue cardboard	25
White blotting paper	82	Brown cardboard	20
White cartridge paper	80	Yellow painted wall, dirty	20
Polished brass	70 to 75	Emerald green paper	18
Mirror backed with Amalgam	70	Dark brown paper	13
Ordinary foolscap paper	70	Vermilion paper	12
Chrome-yellow paper	62	Bluish green paper	12
Orange Paper	50	Cobalt blue paper	12
Yellow wall paper	40	Black paper	5
Yellow-painted wall	40	Ultramarine blue paper	3.5
Light pink paper	36	Black velvet	.4